



WASTE TO ENERGY

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

FINAL REPORT

Prepared for:

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Attention: Tony Wakelin, Section Head Industrial Air Emissions

Dear Mr. Wakelin:

Reference: Waste to Energy: A Technical Review of Municipal Solid Waste Thermal Treatment Practices – Final Report

Attached is the final report *Waste to Energy: A Technical Review of Municipal Solid Waste Thermal Treatment Practices*.

The report was prepared by Stantec Consulting Ltd., with assistance from Rambol Denmark A/S. We also acknowledge the assistance and input from the Ministry of Environment in the preparation of this comprehensive review of the Waste to Energy industry.

On behalf of Stantec, we would like to thank you for the opportunity to be of service to BC Environment in the preparation of this document. We look forward to working with you on similar projects in the future.

Respectfully submitted,

Stantec Consulting Ltd.

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EXECUTIVE SUMMARY

The province of British Columbia is committed to achieving ambitious goals for sustainable environmental management, including realizing greenhouse gas reductions, leading the world with the best air quality bar none and ensuring municipal solid waste (MSW) is managed to minimize environmental impacts. Representing approximately 3% of the province's available biomass resources, a portion of the municipal solid waste stream is a bioenergy source produced in all our communities that has the potential to be used as a fuel supply for the generation of electricity or for the generation of hot water or steam for community energy systems.

Anticipating increased interest in Waste to Energy (WTE) projects, the province is considering updates and revisions to the 1991 Emission Criteria for Municipal Solid Waste Incinerators. This WTE background report supports the Ministry of Environment's scoping phase, and is intended to be used as a supporting document for subsequent steps, including preparation of emission guidelines. This background report addresses the concept of what constitutes good performance, based on best practices in the WTE field in order to provide guidance on potential stack emissions limits and the design and operation of WTE facilities.

The report was prepared through the collaborative efforts of Stantec Consulting Ltd. and Ramboll Denmark A/S. Stantec has direct recent experience with the WTE sector in North America and Ramboll brings thermal treatment experience from the European Union.

The report includes the following main sections:

Thermal Treatment Technologies

A review of the thermal treatment processes applied to the MSW stream has been summarized. Both current, conventional combustion technologies and emerging WTE technologies are described in general terms. Conventional mass burn thermal treatment systems are most common in the industry, with some application of waste gasification, plasma arc and pyrolysis technologies. Emerging technologies include gasplasma, thermal cracking, thermal oxidation and waste-to-fuels technology.

WTE Facility Discharges

The report includes a discussion of typical discharges from WTE facilities, including emissions to the atmosphere, liquid effluent, and solid residues. Air emissions include, but are not limited to, particulate matter (total particulate, PM₁₀ and PM_{2.5}), sulphur oxides (SO_x), nitrogen oxides (NO_x), certain volatile organic compounds (VOCs), and carbon monoxide (CO). The section also describes additional air emissions of interest, sometimes described as Hazardous Air Pollutants (HAPs). These typically include acid gases, organic constituents, trace metals, mercury, polycyclic aromatic hydrocarbons, and dioxins and furans. Point source air emissions (from stacks) and fugitive emission sources are described. The management of liquid wastes produced by WTE facilities is described. The primary potential sources of liquid wastes are certain air pollution control equipment (wet scrubbers). Liquid wastes typically require on-site treatment prior to recycling and/or discharge to the sanitary sewer system.

Air Emission Control Systems

The report reviews air emission control systems commonly applied to thermal treatment technology, including operational controls and air pollution control (APC) system equipment. Operational controls relate to the handling of the MSW and how the operators control the combustion parameters to optimize facility performance. There are a wide variety of primary APC systems available for WTE facilities and typically these are used in combination to minimize the potential emissions. The APC system train selection is generally made after first selecting the scrubber system (dry, semi-dry or wet), and then other components that are complementary to the scrubber selection are added. The use of wet or dry scrubbers to control acid gases has been documented to achieve 87 – 94% removal of HCl and 43 – 97% removal of HF. Nitrogen Oxide control is accomplished using either Selective Catalytic Reduction (SCR) or Selective Non-Catalytic Reduction (SNCR) approaches, which use ammonia to react with oxides of nitrogen in the flue gas to reduce the concentration of NO_x. A reduction of NO_x in the order of >90% is typically achieved for SCR and 30% to over 75% for SNCR. Particulate removal efficiencies of up to 99.9% have been documented for both baghouses and electrostatic precipitators.

Expected Emission Rates

This section provides an overview of the typical emissions rates from combustion and control systems and the factors that affect the quality and quantity of emissions. Reported facility emission data for the WTE sector for facilities in Metro Vancouver, Ontario, USA, China and the European Union are tabulated for comparison. The factors that affect emission concentrations and rates from a WTE facility are discussed in overview.

Refuse Derived Fuel – An Overview

Refuse derived fuel (RDF) has the potential to be used as an industrial facility fuel supply for specific applications. RDF is typically defined as processed MSW, but can also include waste generated through construction and demolition (C&D). Examples of the use of RDF and C&D wastes in power boilers and cement kilns as fuel substitutes is discussed, with specific application to British Columbia. The potential effect of the use of such fuels on emission profiles and rates from industrial facilities are discussed.

Associated Costs and Energy Efficiency

As part of the comparison of WTE technologies, the report includes a review of costs and energy efficiency for the various thermal treatment and APC technologies. The capital and operating cost for WTE facilities varies on a per tonne basis depending on the scale of the facility and specific design parameters. Generally, actual cost information is difficult to verify, and much of the available cost data is based on vendor information that has been provided outside of formal procurement processes. The sale of recovered energy in a WTE facility, in the form of electricity or as heat (steam), is typically critical to the financial viability of the facility, particularly when compared to other MSW management options.

The report includes an overview of the European Energy Equation (Equation) and its application to the WTE sector. The Equation originated with the European Union (EU) Waste Framework Directive

(WFD) and is applied to categorize waste incineration facilities as recovery facilities, as opposed to waste disposal facilities which are lower on the waste hierarchy, where energy recovery/efficiency above a specified target (0.6 to 0.65 in accordance with the Equation) can be shown. Facilities that cannot meet this target are classified as waste disposal facilities. The ministry's Environmental Protection Division operational policy already states a preference for any MSW incineration facilities to meet energy recovery criteria (over disposal, determined using an approach similar the Equation). There are also aspects of the "*The BC Energy Plan: A Vision for Clean Energy Leadership*" related to efficiency and alternative energy within which a similar equation (modified to suit the BC context) could play a role to support development of efficient WTE approaches.

Monitoring Systems

An overview of emission and ambient monitoring systems is provided. This includes continuous emissions monitoring, periodic (non-continuous) source testing and ambient air quality monitoring techniques. References to the applicable monitoring procedures are provided. A discussion on averaging periods for continuous and periodic stack testing methods is included in relation to determining compliance with emission criteria and permit limits.

Emission Limits and Application

The report includes a discussion of the regulatory environment and regulatory practices in various jurisdictions, including Canada, USA and the EU, with specific focus on the generation and application of criteria and permit limits in BC. The Ministry's Environmental Protection Division has an interim Best Achievable Technology (BAT) policy to be used in the identification and setting of new waste discharge standards and criteria. A brief overview of the interim policy is provided.

This section also includes review of regulatory emission limits for Criteria Air Contaminants (CACs) and Hazardous Air Pollutants (HAPs) for the WTE sector. Two tables comparing emission limits are provided. One is a summary of maximum allowable concentrations of CACs and other parameters for WTE facilities as defined by criteria or standards in various jurisdictions. The second table is a comparison of actual permitted limits (from Permits or Certificates of Approval/Authorization) from actual facilities. Typical WTE facilities are capable of achieving emissions that are below maximum permitted hourly or daily average limits.

This section also contains a table summarizing emission limits by parameter and their corresponding averaging periods. The comparison includes the 1991 BC Emission Criteria for Municipal Solid Waste Incinerators, the new Ontario A-7 standard (October 2010), and the European Union's Waste Incineration Directive (WID) limits and 2006 BREF guidelines (European Union Best Achievable Technology Reference Documents).

This section concludes with proposed amendments to the 1991 Emission Criteria for Municipal Solid Waste Incinerators for BC, including the numerical value of the criteria by parameter and the recommended corresponding measurement and averaging methods. The proposed amended guidelines are also provided in the Recommendations (Section 11).

Ash and Residue Management

This section discusses the composition of bottom ash, fly ash and APC residues from WTE facilities. The quality of the residues is directly linked to the quality of the MSW input to the facility and some ash and APC residue quality data from EU facilities is presented. Gasification process residues are also described. The degree of sorting and source separation has a large effect on the quality of the ash. The report discusses beneficial use of these residues, including recovery and recycling of metals and the use of bottom ash as a construction aggregate or as a feedstock to the cement industry.

The section also describes the regulatory environment governing WTE residuals management in BC, North America and the EU. The section then focuses on the specifics for management of ash and residues in BC, including determining if the material is hazardous waste, identifying potential alternative uses, and safe disposal options.

Posting of financial security may be necessary where the land filling of ash from a WTE facility poses a potential risk to the environment. The report discusses in general terms how the need for financial security is determined in BC for contaminated sites and how the value of the financial security is determined. Financial security is based on a site-specific risk determination.

Conclusions and Recommendations

Conclusions and recommendations reached following the review of technologies, BAT, Best Available Control Technology (BACT) and the regulatory approaches in other jurisdictions, and considerations for updates to emissions criteria in B.C. are summarized as follows:

Conclusions

1. Mass burn incineration continues to be the most common method of thermal treatment for WTE facilities. It is reasonable to anticipate that this technology would be proposed for new WTE facilities contemplated in BC.
2. Other thermal treatment technologies such as gasification, plasma gasification and pyrolysis have historically had certain limitations due to their complexity, difficulty in handling variations in the waste stream (which can be managed by waste pre-treatment), and lower net energy recovery (electricity and heat energy) once in-plant parasitic consumption is accounted for. These factors tend to make these other thermal treatment technologies less viable. However, the industry continues to evolve and facilities that treat a portion of the waste stream are being proposed, developed and commissioned. As more actual performance data is generated, it will be better understood if the limitations of these approaches can be resolved.
3. The 1991 BC Emission Criteria for Municipal Solid Waste Incinerators (1991 BC Criteria) cut off between small and large facilities of 400 kg/hour (equivalent to 9.6 tonnes per day) was put in place to differentiate between small facilities used for remote locations and/or on-site waste management and larger WTE facilities. In Europe WTE operations generally handle an average of 20 to 30 tonnes of MSW per hour (480 to 720 tonnes per day). To-date, various studies indicate that it is difficult for commercial WTE facilities to be economically viable at annual capacities less than 10 tonnes per hour (equivalent to 100,000 tonnes per

year actual throughput), unless there is a local economic driver (e.g., high value local market for heat energy, high transportation costs and/or difficult logistics associated with other disposal options). In some jurisdictions (e.g., Ontario) the differentiation between large and small facilities results in differentiation of approvals processes (large WTE requires full Environmental Assessment (EA) Screening, small WTE does not) however, in regards to air emissions the same criterion/limits apply regardless of size to all WTE applications except for very small scale research applications. Other jurisdictions (e.g., United States Environmental Protection Agency (US EPA)) apply different criterion/limits for smaller scale WTE approaches. For the purpose of regulating MSW incineration in the BC context, it seems reasonable that the cut-off of 400 kg/h between small and large facilities should be maintained.

4. The 1991 BC Criteria currently include the key substances of concern that would be released from the main stack (point source) of an existing or new WTE facility. The 1991 BC Criteria do not, however, provide limits for speciated total particulate matter in the 10 micron (PM_{10}) and 2.5 micron ($PM_{2.5}$) size fractions. This approach is consistent with emission limits observed in other jurisdictions evaluated in this report. The value of specifying limits for speciated particulate matter has not been demonstrated and thus limits for these parameters have not been identified in the proposed revisions.
5. The 1991 BC Criteria do not consider fugitive emissions including dust, odour, and Volatile Organic Compounds (VOCs).
6. The specification of temperature and retention time in the combustion zone varies between North America and the EU, although generally these jurisdictions define the combustion zone in a similar fashion (measured after the last point of air injection). In North America, a minimum temperature of 1,000°C with a retention time of 1 second is typical. In the EU, the specification is minimum 850°C with a retention time of 2 seconds. Operated correctly within the design criteria for the incinerator, both specifications should produce an acceptable quality of emission before entering the APC. Flexibility in specifying these operating parameters should be considered and the appropriate balance of temperature and retention time applied on a facility-specific basis.

In most jurisdictions, guidance on design and operation of WTE facilities is provided including recommendations related to combustion temperature and residence time, and also for other parameters such as combustion air distribution, oxygen availability, operation of APC systems and ash management. In these jurisdictions as in BC, the recommendations are not intended to restrict technology development or to dictate facility design or equipment selection. Alternative designs and operating conditions may be proposed for approval, and considered by the regulatory authority, provided that the systems are designed and operated such that the Emission Limit Values (ELVs) can be achieved. Proponents are expected to provide sufficient technical information to the regulatory authority to justify alternative design and operational parameters. Once approved, these parameters are reflected in the operational permit(s) and/or conditions set out for the facility.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices
Final Report
Executive Summary

7. The most common and effective air pollution systems applied to WTE facilities are dry/semi dry, wet and semi wet systems. Several types of “end of pipe” air pollution controls have been applied to WTE facilities. The selection of best technology (either BACT or BAT) depends on the nature of the waste, design of the combustion process, flue gas composition and fluctuation, energy supply, energy recovery and a number of other considerations.
8. Modern WTE facilities are capable of achieving substantial emission reduction through the use of emission control technology. Reductions in the contaminants of concern across the air pollution control system (APC) typically range from 90% up to 99.95% through the application of typical APC systems.
9. Management of NO_x can be accomplished through both Selective Non-Catalytic Reduction (SNCR) and Selective Catalytic Reduction (SCR) systems, with economics in the form of direct costs (including reagent and energy consumption) or financial incentives (e.g., tax regimes) playing a role in the decision regarding which system is selected and in how the system is operated. Lower NO_x emissions can regularly be achieved through SCR. With SNCR, the level of NO_x reduction achieved is often linked to immediate economic drivers since increasing quantities of ammonia injection (i.e., use of additional reagent) are required to achieve lower emission levels. There is also a trade-off with SNCR, as the odour associated with ammonia slippage (stack ammonia releases due to excess ammonia not reacting with NO_x) must be considered.
10. Emission releases from WTE facilities have decreased substantially in the US between 1990 and 2005. SO_x and NO_x have been reduced by 88% and 24% respectively. The reductions have resulted from improvements in thermal treatment technology and operational control, improvements in waste diversion and source separation prior to thermal treatment, and improvements in the design and operation of the APC equipment.
11. The EU Energy Efficiency Equation will be adopted by EU member states by the end of 2010 as a means of differentiating between the energy recovery performance of WTE facilities. In general, the formula can be used for differentiating between energy recovery and disposal within a waste hierarchy. The application of the equation varies between the various EU member states. Further development and definition of the scope and application of the equations is expected. The ministry’s Environmental Protection Division operational policy already states a preference for any MSW incineration facilities to meet energy recovery criteria (over disposal, determined using an approach similar the Equation). Therefore, it may be reasonable to modify the Equation to suit a BC context (i.e., modify the energy equivalency factors for electrical and thermal energy as appropriate) as part of future policy development in the Province. However, new WTE facilities in BC may not be able to achieve an energy efficiency of 60% without further development of infrastructure such as district heating that would facilitate the use of heat generated by a WTE facility, recognizing that a high efficiency is difficult to reach through the production of electricity alone.

12. In regards to the use of Refuse Derived Fuel (RDF) as substitute fuel in existing industrial or power generating facilities, the majority of jurisdictions examined in this study use a regulatory approach that combines some facets of the regulatory environment associated with WTE facilities (e.g., many of the same stack emissions limits, the same AAQO requirements) but also tailor these approaches in a more industry specific fashion. Generally, the approach applied to regulate use of RDF in other jurisdictions includes:
- a) Ensuring that the composition of the RDF is similar in regards to fuel value and general chemical composition to the primary fuel source for the intended combustion facility (e.g., use of cellulosic waste materials in wood-fired boilers).
 - b) Requirement for RDF fuel analysis and comparison to current fuels to determine the potential shift in contaminant mass balance and thus facility emissions.
 - c) The requirement to complete test burns and stack testing to measure and validate predicted shifts in emission quality, if any.
 - d) Application of RDF quality standards, specific to parameters that cannot be reasonably managed in the proposed industrial application (e.g., avoidance of fuels with high PVC content if the control of acid gases is unfeasible).
 - e) Application of the same stack limits applied to WTE facilities, for parameters that are directly associated with fuel quality (e.g., heavy metals, persistent organic pollutants (POPs)) but not for emission parameters that are driven largely by the primary purpose and design of the facility (e.g., not including SO_x emissions for cement kilns as these emissions are largely driven by raw material quality).
13. In the EU, it is common for emission limits to be linked to monitoring techniques and corresponding averaging periods. Typically, one-half hour average limits are specified for parameters measured by continuous monitors, whereas daily average limits are specified for parameters measured by periodic monitoring. For some parameters, limits for both continuous and for periodic monitoring are specified. In the US, daily average emission limits are specified regardless of the monitoring method. The industry trend is towards increased use of continuous monitoring devices where they can be correlated as equivalent to periodic monitoring techniques.
14. In the EU, where one-half hour average limits and daily average limits are specified for a parameter, the one-half hour limit is numerically higher than the daily average limit. The dual limits acknowledge that the daily average takes into account the fluctuations in the emission over time, whereas the one-half hour limit more closely represents the maximum allowable discharge concentration over the shorter averaging period.
15. This report highlights the potential use of the dual standards for some parameters as applied in the EU. When comparing the emission limits proposed in this report to the 1991 BC Criteria, the potential monitoring methods applicable for each parameter must be considered. The proposed limits allow for continuous monitoring where appropriate and technically feasible and in general these values are greater than the daily average. The limits also allow for periodic monitoring for parameters that require stack testing and these

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices
Final Report
Executive Summary

proposed daily average limits are equal to, or more stringent than, the 1991 BC Criteria. New Ministry of Environment policy indicates that all WTE projects will be required to go through an Environmental Impact Assessment process. This is similar to the approach in jurisdictions such as Ontario, where all WTE projects (above a minimum size limit) are required to go through screening under the *Ontario Environmental Assessment Act*.

16. The BC Hazardous Waste Regulation specifies the methodology for testing leachability of a waste material and determining if it is classified as hazardous waste. Bottom ash, fly ash and APC residue should be subjected to the TCLP test and the ash should then be handled according to the classification.
17. Bottom ash is normally not classified as hazardous waste and it is acceptable practice to deposit bottom ash in a permitted sanitary landfill or for the ash to be utilized for a beneficial use, such as intermediate cover, concrete or asphalt aggregate substitution or road base material. Jurisdictions such as Ontario, recognize that bottom ash from facilities that process non-hazardous municipal waste and that has organic content of less than 10%, is a non-hazardous material and do not require that TCLP testing be carried out on such ash. Fly ash and air pollution control (APC) residue are more likely to contain leachable contaminants and be classified as hazardous waste. Fly ash and APC residue must be disposed of in a secure landfill authorized to receive this class of material. Alternatively, the fly ash/APC residue may be pre-treated/stabilized to reduce leachability prior to deposition in a municipal sanitary landfill site. There is limited opportunity for beneficial use of fly ash and APC residues in BC, even when stabilized, at the present time.
18. The Waste to Energy sector continues to evolve with the advent of new incineration and new pollution control equipment technology and the further advances in municipal waste diversion and separation technologies. Regulatory agencies including Ontario Ministry of the Environment and the US EPA have either recently revised or are considering revisions to current regulations and criteria. The BC Ministry of Environment should take into account both the technical and regulatory advances underway in comparable jurisdictions when developing revised guidelines.

Recommendations

1. The 1991 BC Criteria for municipal solid waste incineration should be updated to reflect advancements in thermal treatment and pollution control technology and standards applied in other jurisdictions. A table summarizing the recommended emission limits is provided at the end of this section.
2. It is recommended that the Waste Discharge Regulation (WDR) exemption for remote incinerators to accommodate fewer than 100 persons (section 3(7)) remain in place for remote operations. If a facility is serving over 100 persons and is processing less than 400 kg/hr of municipal solid waste, site specific emission limits should be authorized by the Ministry. Facilities over the 400 kg/hr capacity limit should be required to meet new revised emission guidelines as set by the Ministry.

3. The design and operation requirements in the 1991 criteria should continue to apply including the recommended minimum incineration temperature of 1,000°C and minimum residence time of 1 second (after final secondary air injection ports). This requirement should be maintained as the default specification; however proponents should be provided an opportunity to seek an alternate temperature/retention time specification that would result in equivalent thermal destruction efficiencies without impacting emission quality. Flexibility in the application of the temperature and retention time specification is possible, as long as the quality of the emission is maintained for a specific facility. A minimum temperature of 850°C with a retention time of 2 seconds could be considered equivalent, depending on the proposed technology. Adjustments to the temperature profile and retention time for a proposed facility should be demonstrated as equivalent by a facility proponent at the application stage, and would be reflected in the approved operating conditions set out for the facility.
4. The potential for fugitive emissions from WTE facilities should be addressed through site specific design considerations such as maintaining appropriate areas of the facility (e.g., receiving and tipping floor) under negative pressure, using indoor facility air for combustion and specific measures for loading, transfer, storage, accidental loss of containment, as well as the handling of auxiliary fuels and reagents for the APC systems. Revisions to the 1991 BC Criteria should address fugitive emissions with references to Best Management Plans, meeting ambient objectives and/or odours at the fence-line or other enforceable criteria.
5. The revised emission limits presented at the end of this section (also as Table 8-21) should be considered by the Ministry as proposed new emission criteria for WTE facilities in BC.
6. The recommended revised emission criteria generally reflect two approaches to setting in-stack emissions limits. The one-half hour limit is intended to be used where the facility uses continuous monitoring techniques. The one-half hour limit generally represents the maximum allowable concentration of a contaminant not to be exceeded at any time. The daily average limit applies when periodic stack sampling is used to characterize the emissions. The daily average limit should be considered to be the default limit where the facility must use periodic sampling to determine compliance or where continuous monitoring methods are not available or practical. Both the daily average and one-half hour limits should apply to parameters for which continuous monitoring is feasible and conducted, and where periodic stack sampling is required.
7. The recommended revised emission criteria for particulate, adopts a hybrid approach to emission limit values from other jurisdictions. Where continuous monitoring systems are used, it is proposed that the concentration of total particulate be less than 9 mg/Rm³ for 97% of the operating period on a 12 month rolling average, and less than 28 mg/Rm³ for 100% of the operating period on a 12 month rolling average. Where continuous monitoring systems for particulate are used, opacity monitoring may not be necessary as a compliance parameter unless the continuous monitoring system is not functioning. During this scenario, opacity monitoring can be used as a temporary surrogate until the continuous monitoring system for particulate is reinstated.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Executive Summary

8. The recommended revised emission criteria for trace metals lead (Pb), arsenic (As) and chromium (Cr) should be set as the sum of the three metals as determined by periodic sampling with the ELV being set at 64 ug/Rm^3 .
9. Where a non-MSW thermal treatment facility intends to substitute fuel with RDF, or C&D waste, the facility should be required to meet these revised WTE emission criteria for parameters that are directly associated with fuel quality, such as trace heavy metals and persistent organic pollutants. For particulate emissions, the facility could be required to meet new applicable guidelines (for biomass boilers the Ministry may set new limits of 35 mg/m^3 for facilities ranging in size from 3 to 39 MWh, and 20 mg/m^3 for facilities of 40 MWh and larger). The facility should still meet their permitted emission parameters that are established based on the primary purpose and design of the facility, such as SO_x , CO and NO_x . The range of permitted emission parameters that are established based on the primary purpose and design of the facility will vary as appropriate between specific types of existing industrial installations. This approach is permissive by allowing fuel substitution to occur but also protective by requiring compliance with the appropriate, more stringent, limits for potentially harmful contaminants related to the substituted fuel.
10. Generally, the approach applied to regulate use of RDF in BC should be similar to that used in other jurisdictions, including application of the following sequence of steps during the permitting process:
 - a) Ensuring that the composition of the RDF is similar in regards to fuel value and general chemical composition to the primary fuel source for the intended combustion facility (e.g., use of cellulosic waste materials in wood-fired boilers).
 - b) Requiring RDF fuel analysis and comparison to current fuels within the applications to use RDF, along with analysis that identifies the potential shift in contaminant mass balance and thus facility emissions.
 - c) For use of dissimilar fuels and/or use of RDF where there is some potential for more significant shifts in emissions or concern regarding the degree of emissions shift demonstrated through desk top analysis, in addition to the fuel tests/analysis there should be a requirement to complete test burns and stack testing to measure and validate predicted shifts in emission quality.
 - d) Development and application of RDF quality standards and specifications, specific to parameters that cannot be reasonably managed in the proposed industrial application (e.g., avoidance of fuels with high PVC content if the control of acid gases is unfeasible). This would include development of a definition for various fractions of sorted MSW and construction and demolition waste, for example defining what constitutes 'clean' versus 'contaminated' wood waste suitable for use as a substitute fuel for wood waste boilers.
 - e) Application of the same stack limits applied to WTE facilities, for parameters that are directly associated with fuel quality (e.g., heavy metals, POPs) but not for emission parameters that are driven largely by the primary purpose and design of the facility

(e.g., not including SO_x emissions for cement kilns as these emissions are largely driven by raw material quality). For those parameters that are driven largely by the primary purpose and design of the facility, facility specific ELVs will be determined and applied, potentially resulting in some adjustment to the ELVs for these parameters as set out in the operating permit.

The above represent preliminary recommendations. Further study is required to determine the appropriate RDF fuel quality specifications applicable in BC, and to determine the approach to stack emissions that would be most applicable to each of the major sectors (pulp mill boilers, lime kilns, cement kilns) that would represent industrial users of RDF in BC. The Province should consider development of specific regulatory instruments to address RDF composition (similar to other jurisdictions that regulate RDF composition for various applications) and use as a fuel alternative.

11. Dispersion modelling should be conducted to assess risks associated with the location and potential operation of a new WTE facility. Modelling results should show in all cases that AAQOs established or accepted by the Ministry would not be exceeded with a wide margin of safety for all conceivable modes of operation including upsets.
12. Potential effluent discharges from a WTE facility originating from process wastewater (associated wet flue gas treatment), originating from bottom ash storage, or from other process wastewater streams (boiler feed water, sanitary wastewater, storm water (either contaminated or clean) or used cooling water should be authorized as part of the Solid Waste Management Plan or under a waste discharge permit with limits determined on a site specific basis.
13. The current approach in BC used for leachability testing of bottom ash, fly ash and APC residues is consistent with other jurisdictions. Testing the leachability of the ash continues to be critical in the decision process for reuse and /or disposal of the bottom ash and APC residues. The TCLP leachate extraction test prescribed in the BC HWR is a suitable test method and widely accepted. Bottom ash found to be non-leachable is not hazardous waste and can have some beneficial use or can be deposited in a permitted landfill. APC residue from MSW treatment systems will likely be leachable and require stabilization prior to disposal in a landfill or should be managed as hazardous waste.
14. Separate handling of bottom ash and APC residues represents best practice in order to optimize recovery and/or beneficial use of bottom ash. New incineration technologies should be required to identify the characteristics of the facility residuals. If residuals are determined to have beneficial use characteristics the proponent should demonstrate the associated environmental benefits and liabilities. If beneficial reuse is not practical, consideration for comingling the ash for landfilling, with stabilization as may be necessary, may be permitted.
15. In the development of revised WTE guidelines, BC Ministry of Environment should take into account ongoing technical and regulatory advancements currently evolving in Ontario, the EU and USA.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Executive Summary

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Table 1: Proposed Revisions to Emission Criteria for Municipal Solid Waste Incineration in British Columbia

Contaminant	Concentration Units	RECOMMENDED EMISSION LIMITS				
		C: Continuous P: Periodic ⁽¹⁾	Daily Average	Average Period and Monitoring Method	Half Hourly Average	Average Period and Monitoring Method
Total Particulate Matter (TPM)	mg/Rm ³ @ 11% O ₂	C (P for existing facilities)	9	Existing facilities without CEMS may use the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	9 ⁽²⁾ 28	1/2 hour average as determined by a continuous emissions monitoring system, achieved 97% of the operating period on a 12 month rolling average. 1/2 hour average as determined by a continuous emissions monitoring system, achieved 100% of the operating period on a 12 month rolling average
Carbon Monoxide (CO)	mg/Rm ³ @ 11% O ₂	C	50	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	100	1/2 hour average as determined by a continuous emissions monitoring system
Sulphur Dioxide (SO ₂)	mg/Rm ³ @ 11% O ₂	C	50	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	190	1/2 hour average as determined by a continuous emissions monitoring system
Nitrogen Oxides (NO _x as NO ₂)	mg/Rm ³ @ 11% O ₂	C	190	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	350	1/2 hour average as determined by a continuous emissions monitoring system
Hydrogen Chloride (HCl)	mg/Rm ³ @ 11% O ₂	C	10	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	60	1/2 hour average as determined by a continuous emissions monitoring system
Hydrogen Fluoride (HF)	mg/Rm ³ @ 11% O ₂	P/C	1	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	4	1/2 hour average as determined by a continuous emissions monitoring system ⁽³⁾ .
Total Organic Carbon	mg/Rm ³ @ 11% O ₂	C	10	Calculated as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	20	1/2 hour average as determined by a continuous emissions monitoring system
Arsenic (As)	µg/Rm ³ @ 11% O ₂	P	See Pb, As and Cr group	Calculated as the sum of three metals determined by arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Cadmium (Cd)	µg/Rm ³ @ 11% O ₂	P	7	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Chromium (Cr)	µg/Rm ³ @ 11% O ₂	P	See Pb, As and Cr group	Calculated as the sum of three metals determined by arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Lead (Pb)	µg/Rm ³ @ 11% O ₂	P	See Pb, As and Cr group	Calculated as the sum of three metals determined by arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Sum of Lead (Pb), Arsenic (As), Chromium (Cr)	µg/Rm ³ @ 11% O ₂	P	64	Calculated as the sum of three metals determined by arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Mercury (Hg)	µg/Rm ³ @ 11% O ₂	P or C ⁽⁴⁾	20	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	N.D.	

Contaminant	Concentration Units	RECOMMENDED EMISSION LIMITS				
		C: Continuous P: Periodic ⁽¹⁾	Daily Average	Average Period and Monitoring Method	Half Hourly Average	Average Period and Monitoring Method
Chlorophenols ⁽⁵⁾	µg/Rm ³ @ 11% O ₂	P	1	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Chlorobenzenes ⁽⁵⁾	µg/Rm ³ @ 11% O ₂	P	1	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Polycyclic Aromatic Hydrocarbons ⁽⁵⁾	µg/Rm ³ @ 11% O ₂	P	5	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Polychlorinated Biphenyls ⁽⁵⁾	µg/Rm ³ @ 11% O ₂	P	1	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Total Dioxins and Furans (as PCDD/F TEQ)	ng/Rm ³ @ 11% O ₂	P	0.08	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Opacity ⁽⁶⁾	%	C (P optional for existing facilities)	N.D.		5	1/2 hour average from data taken every 10 seconds, measured by a CEMS

NOTES:
Concentration units: Mass per reference cubic metres corrected to 11% oxygen. Reference conditions: 20°C, 101.3 kPa, dry gas
N.D. = Not Defined
⁽¹⁾ Where Periodic stack test measurements (P) are indicated, the daily averaging period applies. For Continuous monitoring (C), the 1/2 hour averaging period applies. P/C indicates both technologies are available; ELV will be linked to sampling method.
⁽²⁾ 97% of the half-hour average values over an annual rolling average will not exceed 9 mg/Rm³. 100% of the half-hour average values will not exceed 28 mg/Rm³.
⁽³⁾ This requirement may be omitted at the discretion of the Regional Manager should treatment stages for HCl demonstrate that the ELV for HCl is not exceeded.
⁽⁴⁾ Daily Average ELV for mercury applies regardless of monitoring method.
⁽⁵⁾ Proponents may be able to demonstrate that monitoring both Total Organic Carbon (TOC) and Total Dioxin and Furans could negate the need to monitor Chlorophenols, Chlorobenzenes, Polycyclic Aromatic Hydrocarbons and Polychlorinated Biphenyls.
⁽⁶⁾ Opacity will not be required for compliance purposes for facilities utilizing continuous particulate monitoring systems. Opacity monitoring is recommended for operational monitoring purposes. However, monitoring opacity can be used as a temporary surrogate for total particulate monitoring in the event of a particulate monitoring system failure. Under these circumstances, the ELV of 5% opacity over a 1/2 hour averaging period should apply.

TABLE OF CONTENTS

1	Introduction	1-1
1.1	Project Outline.....	1-2
1.2	Project Authors.....	1-3
1.2.1	Stantec Consulting Ltd.	1-3
1.2.2	Ramboll Denmark A/S.....	1-4
2	Thermal Treatment Practices	2-1
2.1	Overview of Thermal Treatment Processes.....	2-1
2.2	Current and Emerging Combustion and Thermal Treatment Practices and Associated Control Technologies	2-4
2.2.1	Current Combustion and Thermal Treatment Technologies	2-4
2.2.1.1	Conventional Combustion	2-5
2.2.1.2	Gasification of MSW.....	2-14
2.2.1.3	Plasma Arc Gasification	2-20
2.2.1.4	Pyrolysis	2-24
2.2.2	Emerging Combustion and Thermal Treatment Technologies	2-27
2.2.2.1	Gasplasma	2-28
2.2.2.2	Thermal Cracking Technology (Fast Pyrolysis)	2-28
2.2.2.3	Thermal Oxidation.....	2-29
2.2.2.4	Waste-to-Fuels.....	2-29
2.2.3	Summary of Major Thermal Treatment Technologies.....	2-30
3	Potential Discharges from Thermal Treatment.....	3-1
3.1	Air Emissions	3-1
3.1.1	Overview of Potential Emission Constituents.....	3-1
3.1.2	Point Source Emissions	3-6
3.1.3	Fugitive Emissions	3-7
3.1.4	Factors Affecting Airshed Impacts.....	3-7
3.2	Liquid Effluents.....	3-8
3.2.1	Physical/Chemical Treatment.....	3-11
3.2.2	In-line Evaporation of Wastewater	3-13
3.2.3	Separate Evaporation of Wastewater	3-14
3.2.4	BAT for Effluent Management	3-15
3.3	Solid Wastes	3-17
3.3.1	Reject Waste	3-17
3.3.2	Bottom Ash.....	3-18
3.3.3	Recycling of Metals	3-18

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Table of Contents

3.3.4	Primary APC Residues.....	3-18
3.3.5	Other APC Residues	3-19
4	Air Emissions Controls	4-1
4.1	Operational Controls	4-1
4.1.1	Operational Controls for Mass Burn Incineration (Conventional Combustion)	4-2
4.1.2	Operational Controls for Gasification Systems	4-6
4.2	Air Pollution Control Systems	4-8
4.2.1	Primary Air Pollution Control System Components.....	4-9
4.2.1.1	Activated Carbon Adsorption (Mercury, Dioxin/Furan Control)....	4-9
4.2.1.2	Fabric Filter Baghouses (Particulate Matter Control).....	4-10
4.2.1.3	Electrostatic Precipitators (ESP) (Particulate Matter Control) ...	4-12
4.2.1.4	Mechanical Collectors (Particulate Matter Control)	4-13
4.2.1.5	Acid Gas Scrubbers (Multi-Pollutant Control)	4-15
4.2.1.6	Nitrogen Oxide Control.....	4-18
4.2.1.7	Conditioning Towers or Wet Spray Humidifiers	4-21
4.2.2	APC System Design and Operation	4-22
4.2.2.1	Dry/Semi-Dry Systems.....	4-23
4.2.2.2	Wet Systems	4-25
4.2.2.3	Semi-Wet Systems.....	4-28
4.2.2.4	NO _x Control System Components	4-29
4.2.2.5	Mercury and Dioxin/Furan Control System Components	4-31
4.2.2.6	Trace Heavy Metal Control System Components.....	4-31
4.2.2.7	Particulate Matter Control System Components.....	4-32
4.2.2.8	Other APC Systems	4-32
4.2.3	APC for Gasification Facilities	4-34
4.3	BACT for APC Systems	4-36
5	Expected Emission Rates from Combustion and Control Systems	5-1
5.1	Typical Emissions from Mass Burn Facilities.....	5-1
5.2	Comparison of Emission Rates from Existing Facilities.....	5-2
5.3	Air Emissions Quality Trends	5-5
5.4	Factors Affecting Emission Rates	5-6
5.4.1	Waste Composition and Content.....	5-6
5.4.2	Selection of Thermal Technology	5-7
5.4.3	Design and Operation of APC Equipment.....	5-7
6	Emissions from Use of Refuse Derived Fuel	6-1
6.1	RDF Overview	6-1

6.2	RDF Use in Wood Fired/Pulp Mill Boilers	6-3
6.2.1	General Discussion	6-3
6.2.2	Use of Wood Waste in Pulp Mill/Wood Fired Boilers	6-4
6.2.3	Use of Tire Derived Fuel in Pulp Mill/Wood Fired Boilers	6-7
6.3	Use of RDF by Cement Kilns	6-8
6.3.1	Regulatory Approach in Ontario	6-14
6.3.2	European Union.....	6-16
6.4	Proposed Regulatory Approach for RDF	6-20
7	Associated Costs and Energy Efficiency	7-1
7.1	Capital Expenditure and Operating Costs.....	7-1
7.1.1	Range of Order of Magnitude Costs	7-2
7.1.1.1	Conventional Combustion	7-5
7.1.1.2	Gasification of MSW.....	7-7
7.1.1.3	Plasma Arc Gasification	7-8
7.1.1.4	Pyrolysis.....	7-8
7.1.1.5	Summary of Capital and Operating Costs	7-9
7.1.2	Cost Differentials between Technologies.....	7-10
7.1.3	Costs Associated with Emissions Control	7-10
7.2	Thermal Efficiency and Energy Recovery	7-11
7.2.1	Energy Recovery from Mass Burn Facilities	7-12
7.2.2	Energy Recovery from Gasification Facilities.....	7-14
7.3	European Union Energy Efficiency Equation Experience.....	7-14
7.4	WTE Energy Recovery and Revenue Streams in BC.....	7-18
7.5	Summary – BAT for Energy Recovery	7-21
8	Emission Monitoring Systems	8-1
8.1	Continuous Emissions Monitoring Systems (CEMS).....	8-1
8.2	Periodic Emission Monitoring.....	8-4
8.3	Commonly Accepted Emission Monitoring Methods	8-5
8.4	Relationship between Monitoring Methods and Emission Limits.....	8-8
8.5	Ambient Air Quality Monitoring	8-9
9	Emission Limits and Their Application	9-1
9.1	Typical Regulatory Practices	9-1
9.1.1	Regulatory Environment in Canada	9-2
9.1.1.1	CCME Guidelines.....	9-2
9.1.1.2	CCME Canada Wide Standards (CWS)	9-2
9.1.1.3	CEAA.....	9-4
9.1.1.4	Summary.....	9-4

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Table of Contents

9.1.2	Regulatory Environment in British Columbia.....	9-5
9.1.2.1	<i>Environmental Management Act</i>	9-5
9.1.2.2	Emission Criteria for Municipal Solid Waste Incineration	9-6
9.1.2.3	BC Ambient Air Quality Objectives	9-10
9.1.2.4	BCMOE Best Achievable Technology Policy	9-14
9.1.2.5	<i>British Columbia Environmental Assessment Act</i>	9-14
9.1.3	Regulatory Environment in Metro Vancouver	9-16
9.1.3.1	Greater Vancouver Regional District Air Quality Management Bylaw No. 1082, 2008	9-16
9.1.3.2	Metro Vancouver Solid Waste Management Plan	9-16
9.1.3.3	Proposed Gold River Power (formerly Green Island) WTE Facility	9-18
9.1.4	Regulatory Environment in Alberta.....	9-20
9.1.5	Regulatory Environment in Ontario	9-21
9.1.5.1	Ontario Guideline A-7.....	9-22
9.1.5.2	O. Reg. 419 Schedule 3 Standards	9-32
9.1.6	United States Environmental Protection Agency	9-33
9.1.7	Regulatory Environment in the State of Oregon	9-35
9.1.8	Regulatory Environment in the State of Washington	9-36
9.1.9	European Union.....	9-38
9.1.9.1	The Waste Incineration Directive (WID).....	9-38
9.1.9.2	The Integrated Pollution Prevention and Control (IPPC) Directive	9-40
9.1.9.3	IED – Industrial Emissions Directive	9-42
9.1.9.4	European Union Member States Regulatory Limits.....	9-43
9.2	Emission Limits for Criteria Air Contaminants and Hazardous Air Pollutants.....	9-44
9.3	Application of Emission Limits in BC.....	9-51
9.3.1	Setting Objectives and Standards for Existing and New Facilities.....	9-51
9.3.2	Operational Variability	9-51
9.3.3	Setting Emission Limits	9-52
9.3.4	Proposed Approach.....	9-52
10	Management of WTE Residues	10-1
10.1	Composition of Residues	10-1
10.1.1	Bottom Ash.....	10-1
10.1.2	APC Residues	10-3
10.1.3	Factors Affecting Ash Composition	10-6
10.1.4	Gasification Residue Management	10-6
10.1.4.1	Nippon Steel “Direct Melting System”	10-7

10.1.4.2	Thermoselect	10-8
10.2	Ash Management Regulations in Europe and North America	10-9
10.2.1.1	European Union	10-9
10.2.1.2	European Union Member States	10-11
10.2.1.3	United States	10-13
10.2.1.4	Canada	10-16
10.3	Management of Bottom Ash and APC Residues	10-21
10.3.1	Safe Disposal of Ash	10-21
10.3.2	Alternative Uses of Bottom Ash	10-22
10.3.3	Treatment and Alternative Use of APC Residues	10-24
10.3.4	Ash Management in Canada	10-27
10.4	Summary – BAT for Management of Residues	10-32
11	Conclusions and Recommendations	11-1
12	Closure	12-1

List of Tables

Table 1:	Proposed Revisions to Emission Criteria for Municipal Solid Waste Incineration in British Columbia	xiii
Table 2-1:	Metro Vancouver and Durham/York Residential Post-diversion Waste Category Breakdown Suitable for WTE	2-2
Table 2-2:	Overview of Conventional Combustion Facilities in Canada that Treat MSW	2-12
Table 2-3:	Conventional Combustion – Summary of Information	2-13
Table 2-4:	Gasification – Summary of Information	2-19
Table 2-5:	Plasma Arc Gasification – Summary of Information	2-23
Table 2-6:	Pyrolysis – Summary of Information	2-27
Table 2-7:	Overview of the Four Major Types of WTE Technologies Used Worldwide	2-30
Table 3-1:	Main Sources of Key Substances of Concern Released from WTE Facilities	3-1
Table 3-2:	Composition of Effluent from MSW Incinerators that Utilize Wet Flue Gas Treatment Systems	3-10
Table 3-3:	BAT Associated Operational Emissions Levels for Discharges of Wastewater from Effluent Treatment Plants Receiving APC Scrubber Effluent ¹	3-16
Table 4-1:	Advantages and Disadvantages Associated with Dry/Semi Dry, Wet, and Semi-Wet Flue Gas Treatment Systems	4-29
Table 4-2:	Advantages and Disadvantages Associated with SNCR and SCR	4-31

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Table of Contents

Table 4-3:	EU BREF: Operational ELV Ranges Associated with the Use of BAT.....	4-39
Table 4-4:	Example of Some IPPC Relevant Criteria for Selection of APC Systems.....	4-40
Table 5-1:	Comparison of Emissions in Raw Flue Gas, EU Emissions Requirements, and Emissions Expected from Semi-Dry, Wet and Semi-Wet APC Systems	5-1
Table 5-2:	Comparison of Emissions from Various Existing WTE Facilities.....	5-3
Table 5-3:	Emissions from Large and Small MWC Units at MACT Compliance (US EPA).....	5-5
Table 5-4:	Impact of Material Removal and Pre-treatment on Residual Waste	5-6
Table 6-1:	Typical Composition of RDF Derived from MSW	6-1
Table 6-2:	Alternative Fuels Regulatory Requirements/Guidelines for Cement Kilns	6-10
Table 6-3:	Types of Alternative Fuels Used in the European Cement Industry.....	6-11
Table 6-4:	Emission Profile from a Cement Kiln Using RDF	6-13
Table 6-5:	Emission Limits for Existing Cement and Lime Kilns Burning Municipal Waste (Guideline A-7)	6-14
Table 6-6:	Summary of BAT for the Cement Industry Relating to the Use of Wastes.....	6-17
Table 6-7:	BAT Emissions Limits for Cement Manufacturing in the IPPC Directive.....	6-18
Table 6-8:	Emissions Limit Values for Cement Kilns in the Waste Incineration Directive	6-20
Table 7-1:	General Distribution of WTE Total Capital Costs	7-3
Table 7-2:	Comparison of Capital Costs for Two Mid-Size WTE Facilities.....	7-7
Table 7-3:	Summary of Reported Capital and Operating Costs for Gasification Facilities (2009\$ CDN)	7-7
Table 7-4:	Summary of Reported Capital and Operating Costs for Plasma Arc Gasification Facilities (2009\$ CDN)	7-8
Table 7-5:	Summary of Reported Capital and Operating Costs for Pyrolysis Facilities (2009\$ CDN)	7-9
Table 7-6:	Summary of Reported Capital and Operating Costs for Common WTE Facilities (2009\$ CDN)	7-9
Table 7-7:	Operational and Capital Costs for Different Emissions Control Systems.....	7-11
Table 7-8:	Energy Potential Conversion Efficiencies for Different Types of Waste Incineration Plants [□]	7-13
Table 7-9:	Potential Energy Generation and Energy Sales for a 100,000 tpy Conventional WTE Facility in a BC Market.....	7-19
Table 8-1:	Continuous Emissions Monitoring in BC, Ontario and EU.....	8-3
Table 8-2:	Approved Emission Monitoring Methods	8-6
Table 9-1:	CCME WTE Emissions Guidelines for Municipal Solid Waste Incinerators (1989).....	9-4

Table 9-2:	BCMOE Emissions Criteria for MSW with a Processing Capacity Greater than 400 kg/h of Waste (1991)	9-7
Table 9-3:	BCMOE Emissions Criteria for MSW with a Processing Capacity Equal to or Less than 400 kg/h of Waste (1991)	9-9
Table 9-4:	BCMOE Design and Operation Requirements for MSW and Emission Control Systems.....	9-9
Table 9-5:	British Columbia, National and Metro Vancouver Ambient Air Quality Objectives	9-12
Table 9-6:	BCEAA Reviewable Projects Regulation Applicable to WTE Projects	9-15
Table 9-7:	Burnaby Incinerator ELVs and Actual Emissions (2007)	9-17
Table 9-8:	Proposed Green Island Energy Emission Limit Values	9-19
Table 9-9:	Air Emissions Limits for the Enerkem Facility	9-21
Table 9-10:	Emissions Requirements, Ontario Guideline A-7 (2004 and 2010).....	9-24
Table 9-11:	Guideline A-7: Design and Operation Considerations for Municipal Waste Incinerators	9-27
Table 9-12:	O. Reg. 419 Schedule 3 Standards and Ambient Air Quality Criteria (2005)	9-33
Table 9-13:	US EPA Emissions Criteria for New and Existing Municipal Waste Combustors.....	9-34
Table 9-14:	Oregon Administrative Rule 340-230-310 Incinerator Regulations – Emissions Limits (April 15, 2010)	9-35
Table 9-15:	WAC 173-434-130 Emission Standards for Solid Waste Incinerator Facilities (2003)	9-37
Table 9-16:	WAC 173-434-160 Design and Operation Requirements for Solid Waste Incinerator Facilities	9-37
Table 9-17:	Emissions Limits for WTE Facilities Set Out in EU Waste Incineration Directive	9-39
Table 9-18:	Comparison of the Requirements of the WID and the BAT Listed in the WI BREF	9-41
Table 9-19:	Comparison of Maximum Allowable Concentration of Pollutants Defined by CCME, BC, Ontario, US, and Europe	9-47
Table 9-20:	Permitted Emission Limit Values from Various Existing and Proposed Facilities Worldwide	9-48
Table 9-21:	Overview of Key Jurisdictions Emission Criteria and Limits with Respect to Averaging Periods.....	9-49
Table 9-22:	Proposed Revisions to Emission Criteria for Municipal Solid Waste Incineration in British Columbia	9-57
Table 9-23:	Rationale for Recommended Values for the ½ Hourly or Daily Averaging Periods.....	9-59

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Table of Contents

Table 9-24:	Comparison of Actual and Proposed Daily and ½ Hourly Monitoring Requirements for the Burnaby Incinerator.....	9-63
Table 10-1:	Composition of Bottom Ash from MSW Incineration in Various Jurisdictions	10-2
Table 10-2:	Typical Composition of APC Residues Resulting from the Combustion of MSW	10-4
Table 10-3:	Residues from Thermoselect Process.....	10-8
Table 10-4:	Composition of Mineral Granulate Produced by Thermoselect Process (Karlsruhe, Germany)	10-8
Table 10-5:	List of Toxicity Characteristic Contaminants and Regulatory Levels.....	10-14
Table 10-6:	Overview of Principles and Methods of Treatment of Ash Residues Resulting from the Thermal Treat of MSW [□]	10-22
Table 10-7:	Quantity of Bottom Ash Produced and Utilized in Various Countries Worldwide	10-23
Table 10-8:	Overview of Management Strategies Used for APC Residue in Various Countries [□]	10-24
Table 10-9:	Generated Quantity and Utilization/Disposal of MSW Bottom Ash and Fly Ash in Canada in 2006	10-28
Table 10-10:	TCLP Results for Metro Vancouver Burnaby MSW Stabilized Fly Ash and APC Residues and BC HWR Leachate Quality Standards (mg/L).....	10-29
Table 11-1:	Proposed Revisions to Emission Criteria for Municipal Solid Waste Incineration in British Columbia	11-9

List of Figures

Figure 2-1:	Schematic Overview of the Role of Thermal Treatment in Waste Management.....	2-1
Figure 2-2:	Overview of Conventional WTE.....	2-3
Figure 2-3:	Overview of Advanced Thermal Treatment WTE	2-3
Figure 2-4:	Conceptual Overview of a Modern Single-Stage Mass Burn Incinerator	2-6
Figure 2-5:	Example of a Grate Incinerator with a Heat Recovery Boiler	2-7
Figure 2-6:	Schematic Overview of a Two-Stage Incinerator	2-9
Figure 2-7:	Schematic Overview of a Fluidized Bed Incinerator	2-10
Figure 2-8:	Conceptual Overview of a High Temperature Waste Gasifier [□]	2-15
Figure 2-9:	Conceptual Overview of a High Temperature Waste Gasifier (Nippon Steel).....	2-17
Figure 2-10:	Conceptual Overview of Alter NRG Plasma Gasification Unit.....	2-21
Figure 2-11:	Conceptual Overview of the Plasco Process.....	2-22
Figure 2-12:	Schematic Overview of the Compact Power Pyrolysis Process.....	2-26

Figure 3-1:	Schematic Illustrating Physical/Chemical Treatment of Wastewater from a Wet APC System [□]	3-12
Figure 3-2:	Schematic Illustrating In-line Evaporation of Wastewater [□]	3-14
Figure 3-3:	Schematic Illustrating Separate Evaporation of Wastewater [□]	3-15
Figure 4-1:	Control Components of a Modern Furnace Control System	4-4
Figure 4-2:	Conceptual Schematic Diagram of Covanta VLN TM Process	4-6
Figure 4-3:	Conceptual Diagram of Operational Controls Used by Nippon Steel.....	4-8
Figure 4-4:	Schematic Overview of a Pulse-Jet Fabric Filter Baghouse.....	4-11
Figure 4-5:	Conceptual Overview of an ESP	4-12
Figure 4-6:	Schematic Overview of Cyclone Separator	4-14
Figure 4-7:	Schematic Overview of a Venturi Scrubber	4-16
Figure 4-8:	Overview of a Circulating Dry Scrubber	4-18
Figure 4-9:	Diagram of a Selective Catalytic Reducer	4-20
Figure 4-10:	Overview of SNCR System.....	4-21
Figure 4-11:	Schematic Overview of a Dry/Semi-Dry APC System.....	4-23
Figure 4-12:	Dry APC System	4-24
Figure 4-13:	Semi-Dry System, Example 1	4-24
Figure 4-14:	Semi-Dry System, Example 2.....	4-25
Figure 4-15:	Schematic Overview of a Wet APC System	4-25
Figure 4-16:	Wet APC System, (a).....	4-27
Figure 4-17:	Wet APC System, (b).....	4-27
Figure 4-18:	Wet APC System (c).....	4-28
Figure 4-19:	Schematic Diagram of the Turbosorp® Turboreactor.....	4-33
Figure 4-20:	Schematic Diagram of the NID System	4-34
Figure 6-1:	Consumption of Different Types of Hazardous and Non-hazardous Waste Used as Fuels in Cement Kilns in the EU-27	6-11
Figure 7-1:	Comparison of Capital Costs for WTE Facilities per Installed Capacity.....	7-3
Figure 7-2:	Range of Operational Costs for WTE Facilities in the EU	7-4
Figure 7-3:	Relationship of Heat to Power Production for WTE Facilities	7-17
Figure 10-1:	Composition of Slag and Metal from Nippon Steel “Direct Melting” Furnace	10-7

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Table of Contents

List of Appendices

Appendix ADatabase of Current Technology Vendors and Thermal Treatment Technologies
Appendix B BC Emission Criteria for MSW Incinerators (June 1991)

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GLOSSARY

AAQC	Ambient Air Quality Criteria
AAQO	Ambient Air Quality Objectives
APC	Air Pollution Control
APC residues	Air Pollution Control residues comprise: (i) dry and semi-dry scrubber systems involving the injection of an alkaline powder or slurry to remove acid gases and particulates and flue gas condensation/reaction products (scrubber residue); (ii) fabric filters in bag houses may be used downstream of the scrubber systems to remove the fine particulates (bag house filter dust); and (iii) the solid phase generated by wet scrubber systems (scrubber sludge). APC residues are often combined with fly ash.
BACT	Best Available Control Technology meaning the technology that can achieve the best discharge standards relative to energy, environmental and economic impacts. BACT is often used more specific for 'end of pipe' control technologies such as Air Pollution Control systems, as opposed to BAT which can also refer to operating systems.
BAT	<p>Best Achievable Technology or Best Available Technology. Best Available Technology represents the most effective techniques for achieving a high standard of pollution prevention and control. BAT mechanisms in the USA and the EU are designed to provide flexibility to balance technical and economic feasibility, and weigh the costs and benefits of different environmental protection measures. This approach is referred to as Best Achievable Technology.</p> <p>BCMOE has an interim Best Achievable Technology policy to be applied when setting new discharge parameters for any discharge media and to be used as the basis for setting site specific permit limits.</p> <p>Within the EU, the concept of BAT was introduced as a key principle in the IPPC Directive 96/61/EC (Directive 2008/1/EC codified version).</p>
BATAEL	Best Achievable Technology (or Best Available Technology) Associated Emission Levels
BCEAA	<i>British Columbia Environmental Assessment Act</i>
BCMOE	British Columbia Ministry of Environment
Bottom Ash	Comprises heterogeneous material discharged from the burning grate of the incinerator (grate ash) and material that falls through the burning grate to be collected in hoppers below the furnace (grate riddlings).

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Glossary

BPEO	Best Practicable Environmental Option is a set of procedures adopted by Great Britain which considers a range of environmental, social and economic factors that should be taken into account when making decisions on the future management of waste.
BREF	European Union Best Available Technology Reference Documents
CAC	Criteria Air Contaminants
CEAA	Canadian Environmental Assessment Agency
CFBC	Circulating Fluidized Bed Combustion is a combustion system in which the fuel (usually processed waste fuels such as coarse refuse-derived fuel) are burned within a bed of fine inert material fluidized by a high velocity air stream. The off-gas and entrained solids are separated in a high efficiency cyclone and the solids are returned to the bed.
CHP	Combined Heat and Power produces electricity and heat in the same process.
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
Co-disposal	Co-disposal is the practice of mixing wastes of different origins in the same landfill or other disposal facility.
Criteria	Criteria, Standards and Guidelines are used often interchangeably and sometimes incorrectly in BC. Criteria and Guidelines are target levels established by good practice and determined to be protective of the environment. Standards are limits established by regulation. It should be noted that in the 1990s the Ministry referred to stack emission standards as “criteria”. These are now currently referred to as “guidelines”.
DEFRA	Department for Environmental and Rural Affairs (UK)
DOC	Dissolved Organic Carbon is organic material, from the decomposition of plant and animal material, dissolved in water.
EC	European Commission is the executive body of the European Union. The body is responsible for proposing legislation, implementing decisions and upholding the Union’s treaties and general operation of the Union.
EFW	Energy from Waste, also known as waste to energy (WTE), is the conversion of waste into a useable form of energy, e.g., heat or electricity. A common conversion process is waste combustion.

ELVs	Emission Limit Values, equivalent to permit limits
EMA	<i>Environmental Management Act</i> is an authorization framework intended to protect human health and the quality of water, land and air in British Columbia. EMA enables the use of administrative penalties, informational orders and economic instruments to assist in achieving compliance.
ESP	Electrostatic Precipitator is a particulate collection device that uses the force of an induced electrostatic charge to remove particles from a flowing gas.
EU	European Union is a political and economic union of 27 member states.
FGT	Flue Gas Treatment
FBC	Fluidized Bed Combustion is a combustion system in which a fine inert material, such as sand, is maintained in a fluid condition by air blowing upwards through it. Used in combination with processed waste fuels, such as coarse refuse-derived fuel.
Fly Ash	Finely divided particles of ash which are normally entrained in the combustion gases. Fly ash is recovered from the gas stream by a combination of precipitators and cyclones.
GEM	Graveson Energy Management
GHG	Greenhouse Gases
GVRD	Greater Vancouver Regional District
HAP	Hazardous Air Pollutants
HF	Hydrogen Fluoride
HWR	Hazardous Waste Regulation enacted under the BC EMA for managing hazardous waste.
IAWG	International Ash Working Group
IEA	International Energy Agency an intergovernmental organization which acts as energy policy advisor to 28 member countries in their effort to ensure reliable, affordable and clean energy for their citizens.
IPPC	Integrated Pollution Prevention and Control
ISWA	International Solid Waste Association

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Glossary

ISWRM	Integrated Solid Waste and Resource Management
LAP	Landelijk Afvalbeheer Plan
Mass-Burn Incineration	The incineration of waste in a grate combustion system
Monofill	Landfill site practice whereby only one type of waste material (e.g., MSW bottom ash) is placed in landfill.
MSW	Municipal Solid Waste is waste which is collected for treatment and disposal by a local authority. MSW generally comprise waste from households, civic amenity sites, street-sweepings, local authority collected commercial waste, and some non-hazardous industrial waste.
MW	Megawatts (10^6 W) is a unit of power equal to one million watts
NCV	Net Calorific Value
NO _x	Mono-nitrogen oxides (NO and NO ₂). These oxides are produced during combustion.
NPRI	National Pollutant Release Inventory is Canada's legislated publicly accessible inventory of pollutant releases (to air, water and land), disposals and transfers for recycling.
PAH	Polycyclic aromatic hydrocarbons consist of fused aromatic rings and do not contain heteroatoms or carry substituents.
PCB	Polychlorinated biphenyls consist of 1 to 10 chlorine atoms attached to biphenyl, which is a molecule composed of two benzene rings.
PCDD	Polychlorinated dibenzo-p-dioxins
PCDF	Polychlorinated dibenzofurans
PM _{0.1}	Particulate Matter consisting of airborne particles with a mass median diameter less than 0.1 micrometers. Includes as a sub-set nanoparticles (<10 nm or 0.001 micrometers)
PM _{2.5}	Particulate Matter consisting of airborne particles with a mass median diameter less than 2.5 micrometers.
PM ₁₀	Particulate Matter consisting of airborne particles with a mass median diameter less than 10 micrometers

Pozzolan	A silica-rich or silica and alumina-rich material which in itself possesses little or no cementaceous value, but which will, in finely divided form and in the presence of moisture, react chemically with calcium hydroxide to form compounds possessing cementaceous properties.
RDF	Refuse Derived Fuel is a fuel product recovered from the combustible fraction of household waste.
REOI	Request for Expressions of Interest
Rm ³	Referenced cubic metre, representing a standard volume of gaseous emission at the reference conditions specified in a jurisdiction
SCR	Selective Catalytic Reduction is a method used to reduce NO _x to N ₂ and H ₂ O through the injection of ammonia into the flue gas stream which then reacts with NO _x within a catalyst bed.
SNCR	Selective Non-Catalytic Reduction is a method to lessen nitrogen oxide emissions in conventional power plants that burn biomass, waste and coal, through the injection of ammonia into hot flue gases at a suitable temperature range to support the chemical reaction to convert NO _x to N ₂ and H ₂ O.
SO _x	Oxides of Sulphur
SRF	Solid Recovered Fuel (interchangeable with RDF) being a fuel product recovered from the combustible fraction of household waste.
SSO	Source Separated Organics
SWMP	Solid Waste Management Plan, prepared for each Regional District in BC, and including the authorization to operate a municipal solid waste landfill
Syngas	The name given to a gas mixture synthesized from waste materials that contains varying amounts of carbon monoxide and hydrogen (but may contain smaller amounts of other gases)
TCDD	2,3,7,8-Tetrachoro dibenzo-p-dioxin
TEQ basis	2,3,7,8-Tetrachoro dibenzo-p-dioxin toxic equivalent, based on the 1989 International toxic equivalency factors
TOC	Total Organic Carbon, is the amount of carbon within organic molecules (carbon chains or rings that also contain hydrogen) versus inorganic molecules (e.g., carbon monoxide, carbon dioxide, carbonates). In regards to air emissions a portion of TOC would be comprised of VOCs (see below).

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Glossary

TWG	Thematic Working Group
TWh	Terawatt hours (10^{12} Watt hours)
UK	United Kingdom
US EPA	United States Environmental Protection Agency founded to protect human health and to safeguard the natural environment including air, water, and land.
VOC	Volatile Organic Compounds are organic substances of concern (carbon chains or rings that also contain hydrogen) that have high enough vapour pressures under normal conditions to significantly vapourize and enter the atmosphere (i.e., with a vapour pressure greater than 2mm of mercury (0.27 kPa) at 250°C or a boiling range of between 60 and 250°C) excluding methane.
WAG	Welsh Assembly Government
WFD	Waste Framework Directive
WHRG	Waste Heat Recovery Generator
WID	Waste Incineration Directive
WTE	Waste to Energy, also known as Energy from Waste (EFW) is the conversion of waste into a useable form of energy, e.g., heat or electricity. A common conversion process is waste combustion.

1 INTRODUCTION

The province of British Columbia is committed to sustainable environmental management including leading the world in air quality. In fact, one of the province's five Great Goals for a Golden Decade^[1] is to “*lead the world in sustainable environmental management, with the best air and water quality, and the best fisheries management, bar none*”. Through airshed management planning, industrial emission standards, and a host of local air initiatives progress is being made toward this goal for air quality.

The province has also made significant climate change commitments. The 2007 *Greenhouse Gas Reduction Targets Act* (GGRTA) sets legislative targets for immediate action toward reducing greenhouse gas emissions. The act sets a GHG emissions reduction target of 33% for 2020 and 80% for 2050, with low interim targets leading up to 2020. The province has taken a number of proactive steps toward reducing GHGs from all sectors including introducing a carbon tax and developing the framework for a cap and trade system for large emitters. These are outlined in the BC Climate Action Plan.^[2]

The BC Bioenergy Strategy^[3] supports the shift from carbon-intensive fossil fuels to biomass fuels as a practical approach to a low-carbon future. The growth in community energy projects and the establishment of municipal landfill methane gas capture systems are both initiatives that demonstrate the commitment to bioenergy in BC today. MSW represents up to 3% of the province's available biomass resources, recognizing that a portion of the municipal solid waste stream is biomass. Various measures can be used to manage the biomass portion of the MSW stream such as recycling, composting and anaerobic digestion. However, experience in other jurisdictions indicates that even with such programs, a portion of MSW would continue to be comprised of biomass.

Waste to energy facilities, which produce heat and power through thermal treatment of MSW, could be used to recover energy from MSW including the biomass fraction. Carbon pricing (established through carbon tax and/or a cap and trade program) may make a Waste to Energy project more financially favourable if the project reduces emissions compared to a business-as-usual scenario in the process of producing power. However, the province has yet to determine how GHG emissions reduction policy will apply to municipal landfills and Waste to Energy operations.

The Waste Discharge Regulation, under the BC *Environmental Management Act*, includes a definition for “municipal waste incineration or burning industry” as an activity that would be allowable in the province with appropriate waste discharge authorizations in place.^[4] To date, the Metro Vancouver Burnaby incinerator is the only sizeable WTE facility in BC. The emission limits for this facility are

¹ British Columbia Strategic Plan 2010/2011 – 2012/2013. Website: http://www.bcbudget.gov.bc.ca/2010/stplan/2010_Strategic_Plan.pdf

² BC Climate Action Plan. Website: <http://www.livesmartbc.ca/government/plan.html>

³ BC Bioenergy Strategy, BC Ministry of Energy, Mines and Petroleum Resources, 2007

⁴ BC *Environmental Management Act*. Waste Discharge Regulation. Website: http://www.bclaws.ca/Recon/document/freeside/--%20e%20--/environmental%20management%20act%20sbc%202003%20c.%2053/05_regulations/50_320_2004.xml

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 1: Introduction

contained in the 1995 Greater Vancouver Regional District Solid Waste Management Plan (SWMP).^[5] Emission criteria for municipal solid waste incinerators were produced by the province in 1991 to be used as a basis for setting SWMP or permit limits for these facilities. The emission limits for the Burnaby incinerator contained in the GVRD SWMP are consistent with these criteria.

This report provides a technical review of the leading municipal solid waste thermal treatment practices currently in use globally and a summary of the associated emission criteria and standards for those technologies. The report also reviews the management of residuals from waste to energy facilities. Finally, the report provides a set of conclusions and recommendations for the province to consider in the development of current guidelines for WTE facilities.

1.1 Project Outline

Waste to Energy, or WTE, typically involves the conversion of solid waste to energy resulting in the generation of electricity from the recovered heat, and/or the generation of hot water or steam to be used for community-based industrial, commercial or residential heating applications. WTE technology has been adopted in many jurisdictions globally and has merit for consideration in BC.

The BC Ministry of Environment (BCMOE) Environmental Protection Division has adopted an interim policy “Determining Best Achievable Technology Standards” that provides guidance on the setting of emissions criteria, standards or regulations. The intent of the policy is to promote the use of best achievable technologies (BAT) in new and existing facilities, and to set criteria and/or permit limits in accordance with BAT.

There are seven steps to determine BAT to be considered in the setting of standards and criteria for the province and for facilities. These steps include:

1. Identification of all potential technologies or options
2. Eliminating technically infeasible options
3. Consideration of the reliability of each option
4. Ranking of technically feasible options by control effectiveness
5. Consider the cost effectiveness of each option
6. Selection of the appropriate BAT for the specific application
7. Determining the appropriate waste discharge criteria or standard.

This report is intended to provide background information on items 1 through 6, and has been structured as follows:

- **Section 2** examines the thermal treatment technologies currently in use globally, and examines emerging technologies that may gain increasing market share in the future.

⁵ 1995 Greater Vancouver Regional District Solid Waste Management Plan. Website:
<http://www.metrovancouver.org/about/publications/Publications/SolidWasteManagementPlan1995.pdf>

- **Section 3** provides an overview of the potential discharges from WTE facilities, including air emission constituents and liquid and solids wastes.
- **Section 4** discusses air emission controls.
- **Section 5** discusses the expected emission rates from WTE facilities, including a summary of actual emissions from facilities operating worldwide.
- **Section 6** discusses the use of Refuse Derived Fuel (RDF), potential emissions from RDF applications and identifies a proposed regulatory approach for RDF.
- **Section 7** discusses the efficiencies and costs of thermal treatment based on available information. It also discusses the use of energy efficiency equations for differentiating between energy recovery and disposal systems under a waste management hierarchy.
- **Section 8** provides an overview of air emission monitoring systems, including continuous emission monitoring, stack sampling and ambient air quality monitoring.
- **Section 9** discusses the regulatory environment governing the WTE sector and how revisions to emissions criteria, standards and permit limits are set in BC according to Best Achievable Technology policy. International, national and regional aspects of emissions management are reviewed, with comparisons of the various objectives, criteria and standards in place across these jurisdictions. A compilation table of various emission limits has been provided to highlight the BC situation relative to other jurisdictions. This section concludes with proposed amendments to the existing BC 1991 Emission Criteria for Municipal Solid Waste Incineration.
- **Section 10** discusses residuals management, including fly ash, bottom ash, pollution control system residuals and gasification process residuals, from various global jurisdictions including the BC experience. Beneficial reuse of ash and safe disposal are discussed. For the BC situation, there is also discussion on the setting of financial security relative to environmental risk for facilities receiving fly ash.
- **Section 11** contains the recommendations to be considered by BCMOE in the setting of amended criteria and standards for the WTE sector in BC.

1.2 Project Authors

1.2.1 Stantec Consulting Ltd.

Stantec was founded in 1954 providing environmental services in Western Canada. Since then it has grown into a full service engineering firm with over 10,000 employees in 150 offices throughout North America. With specific reference to environmental remediation, Stantec has over 1,000 employees completing environmental remediation projects each day.

This capacity allows Stantec to offer our clients enhanced services and greater local presence with global reach. We provide our clients with consistent, safety conscious, high-quality services and personnel they have come to expect and rely on. These services are backed up by experts in their

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 1: Introduction

field practicing in varied disciplines and geographies bringing the knowledge of many to your project. Stantec's multidisciplinary suite of services in environmental site assessment, remediation, landfill design, landfill monitoring, environmental sciences, sustainability, and geotechnical and materials engineering complement one another, heightening our ability to serve clients throughout the project life cycle from conception to closure.

Principle authors of this report were Janine Ralph and Eric Windhorst of the Stantec, Burlington, ON office and Douglas Whiticar, Magdalena Kingsley, Sarah Willie and Kelly Carswell of Stantec, Burnaby, BC. Senior review was completed by David Payne of Stantec, Burlington and Peter D. Reid of Stantec, Calgary, AB.

1.2.2 Ramboll Denmark A/S

Ramboll Group A/S of Denmark, is a consulting company which was founded in 1945. The Ramboll Group has approximately 9,000 employees and is the largest Northern European consulting group. The Ramboll Group specializes in a broad variety of consulting services with WTE as one of the key fields of expertise. Ramboll has worked in the WTE business for more than four decades and has during this period assisted in implementing more than 70 WTE facilities worldwide.

Ramboll is at present involved in more than 30 ongoing WTE projects. The projects are at various stages from project definition through to procurement and supervision during construction, commissioning and follow-up on operation and maintenance which gives an excellent hands-on knowledge of both technology systems and regulatory matters.

Ramboll is member of national and international WTE associations. As active members of the working groups under these associations Ramboll has been directly involved in the discussion with the European Union on regulatory matters.

One of Ramboll's staff is known internationally for his work on the thermal treatment of waste with the European Commission (EC), where for three years he was leader of the EC BAT expert working group of over 100 people. This group was responsible for the production of the official EC guidance on the Best Available Techniques (BAT) for the thermal treatment of wastes, the "BREF" (2006).

Ramboll staff contributing to this report included Bettina Kamuk and Soren Dalager with input from various other staff.

2 THERMAL TREATMENT PRACTICES

This section describes the technology currently available and in use globally for the thermal treatment of MSW. This section also provides information on new and emerging technologies that may not have proven track record, but should be considered in context with existing technologies.

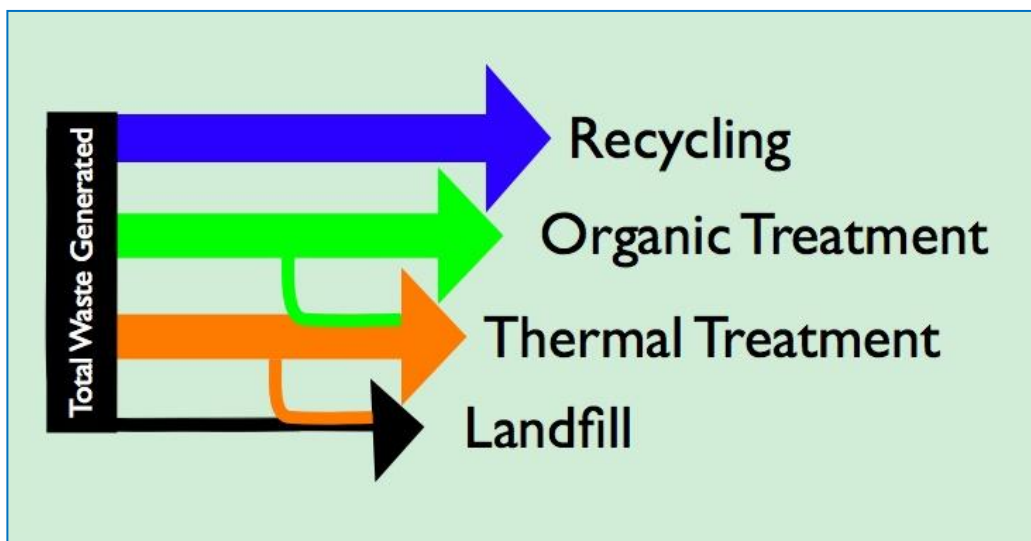
2.1 Overview of Thermal Treatment Processes

The thermal treatment of solid waste is only one part of an integrated waste management system. Thermal treatment can play a number of important roles in an integrated waste management system. Thermal treatment can:

- Reduce the volume of waste, therefore preserving landfill space (thermal treatment does not replace the need for landfills as various residuals still need disposal).
- Allow for the recovery of energy from the solid waste stream.
- Allow for the recovery of minerals and chemicals from the solid waste stream which can then be reused or recycled.
- Destroy a number of contaminants that may be present in the waste stream.
- Often, reduce the need for the “long-hauling” of waste.

In most jurisdictions, thermal treatment of waste is applied to manage the remaining waste stream after source-separated diversion of recyclables and organics. Figure 2-1 presents a schematic diagram illustrating how thermal treatment fits into a conventional waste management system that includes source-separated recycling and organics diversion components.

Figure 2-1: Schematic Overview of the Role of Thermal Treatment in Waste Management



Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 2: Thermal Treatment Practices

As noted in Figure 2-1, it is typical in many jurisdictions that WTE is used to manage the majority of post-diversion residual wastes. The diversion of recyclables and organic materials often results in an overall increase in the heat value of the remaining waste stream, rendering it suitable for potential use in WTE applications.

Table 2-1 presents an example of a typical post-recycling residual MSW stream that could be suitable for WTE in BC (Metro Vancouver), and an example of the composition of a typical post-recycling and SSO diversion residual MSW stream in a typical municipal jurisdiction with expanded diversion programs (Durham/York). The estimates for the Durham/York waste stream represent the typical residual waste composition in Ontario for a municipal jurisdiction with a mature source separated recycling and source-separated organic collection and processing system. The portion of the waste stream that is generally comprised of biomass generally does decrease following introduction of SSO programs. However, the remaining garbage should still be expected to have a reasonable proportion of biomass materials.

Table 2-1: Metro Vancouver and Durham/York Residential Post-diversion Waste Category Breakdown Suitable for WTE

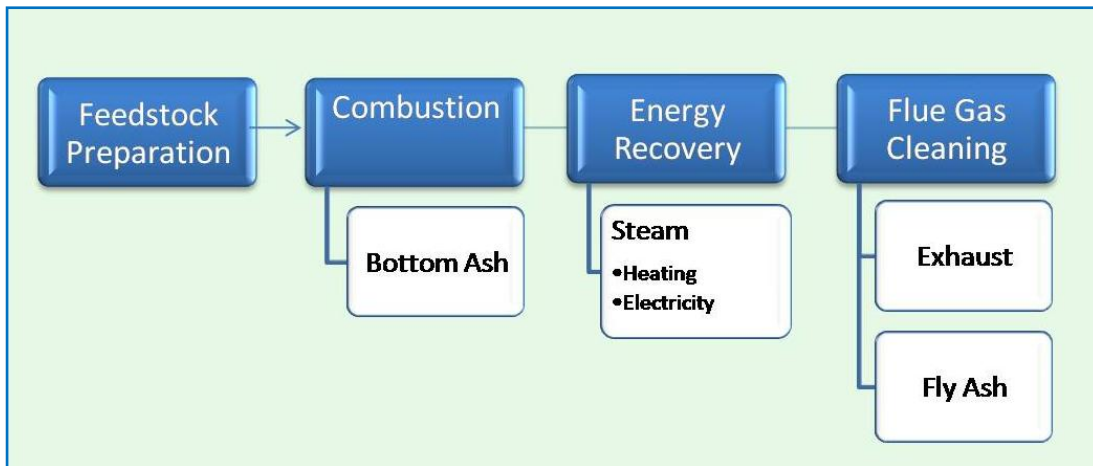
Waste Category	Metro Vancouver Residential Post-diversion (w/o Organics Diversion) (2007) % Composition ^[6]	Durham/York Residential Post-diversion (with Organics Diversion) (2011 Estimates) % Composition ^[7]
Paper	16.7%	18.1%
Plastics	10.2%	12.4%
Metals	1.5%	2.3%
Glass	4.5%	3.9%
HHW	0.4%	0.3%
Organics (food waste, grass, yard waste)	30.2%	13.6%
Animal waste	1.3%	6%
Textiles	1.1%	2.4%
Building renovations	13.3%	4% (includes wood)
Furniture/Bulky goods	3.9%	21.5%
White goods	0.01%	0%
Sanitary products	3.3%	8.7%
Electronics/appliances	2.3%	0.2%
Other	1.8%	6.5%
Wood	9.5%	Not Defined
Approximate % Biomass	60%	50%

⁶ Technology Resource Inc. 2008. SOLID WASTE COMPOSITION STUDY for Metro Vancouver (Greater Vancouver Sewerage and Drainage District)

⁷ Stantec Consulting Limited. Durham/York Environmental Assessment (EA) Study Document as Amended November 27, 2009

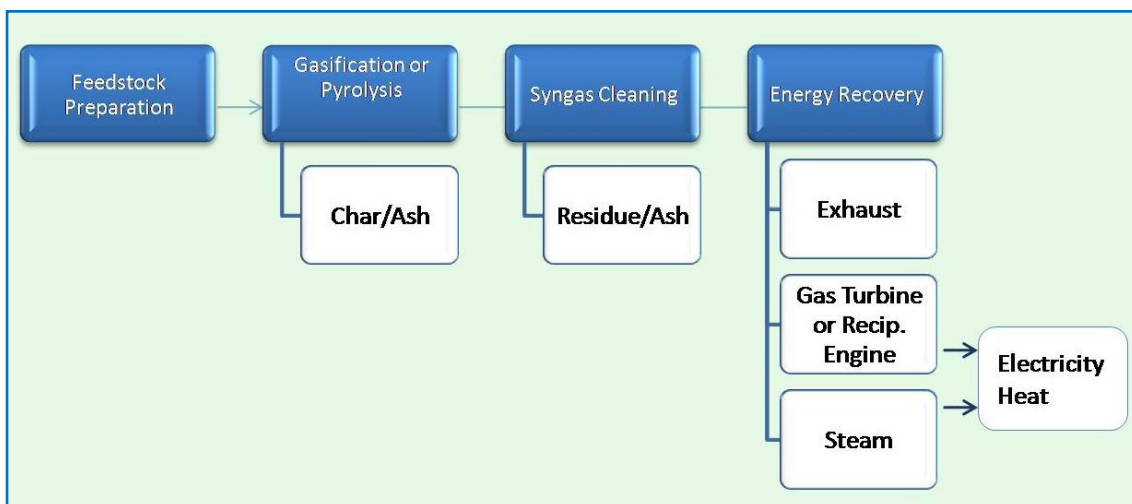
Thermal treatment covers a range of technologies that extract energy from the waste while reducing its volume and rendering the remaining fraction mostly inert. These technologies can be generally grouped into two main categories: conventional combustion and advanced thermal treatment. Conventional combustion technologies include mass burn incineration and fluidized bed incineration among others. Mass burn incineration is the most common type of WTE technology used worldwide. Figure 2-2 provides a simple flow diagram of a conventional WTE approach.

Figure 2-2: Overview of Conventional WTE



Advanced thermal treatment technologies include gasification, pyrolysis and plasma gasification. These technologies tend to be less proven on a commercial scale and involve more complex technological processes. Figure 2-3 provides a simple flow diagram of an advanced thermal treatment WTE approach.

Figure 2-3: Overview of Advanced Thermal Treatment WTE



Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 2: Thermal Treatment Practices

Thermal treatment of MSW involves the oxidation of combustible materials found within the waste. Generally speaking, there are three main stages of any thermal treatment process:

- **Drying and degassing** – here, volatile content is released at temperatures generally between 100 and 300°C. The drying and degassing process are only dependent on the supplied heat.
- **Pyrolysis and gasification** – pyrolysis is the further decomposition of organic substances in the absence of added oxygen at approximately 250 – 700°C which results in the production of syngas (a gas mixture consisting primarily of H₂ and CO), tars (high molecular mass hydrocarbons), and char. Gasification is the partial thermal degradation of organic substances in the presence of oxygen but with insufficient oxygen to oxidize the fuel completely (sub-stoichiometric conditions). Gasification occurs at temperatures, typically between 500 – 1,000°C and results in the in the formation of syngas. Overall, this stage results in the conversion of solid organic matter to the gaseous phase.
- **Oxidation** – the combustible gases (i.e., syngas) created in the previous stages are oxidized, depending on the selected thermal treatment method, at temperatures generally between 800 and 1,450°C.

Typically, these individual stages overlap but they may be separated in space and/or time depending on the particular thermal treatment process being considered.^[8]

2.2 Current and Emerging Combustion and Thermal Treatment Practices and Associated Control Technologies

This subsection reports on a literature and market review of current and emerging combustion and thermal practices and their associated emission control technologies. It concisely summarizes the state-of-the-art in thermal treatment. A brief overview of the range of technologies in the marketplace for which there are current operating facilities is provided. Also noted is the stage of development of the technology (i.e., pilot or full-scale) and the availability of supporting technical information.

2.2.1 Current Combustion and Thermal Treatment Technologies

A comprehensive literature review was conducted by Stantec with input from Ramboll, to determine candidate technologies and vendors for the treatment of residual MSW, resulting in the development of a database of over 100 vendors and technologies. The literature review retrieved reports from various government and vendor websites as well as sources held by Stantec. A number of cities and counties (i.e., City of Los Angeles, New York City, City and County of Santa Barbara, Metro Vancouver) have completed in-depth studies and reviews regarding alternative waste treatment approaches. It is important to note that much of the information that was generally available is vendor information provided through “Requests for Expressions of Interest” (REOIs) and other

⁸ European Commission. 2006. Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration

means and therefore it has not necessarily been verified through a third party and/or verification is not readily available.

Some of the technology information has also been derived from proposals by respondents through Requests for Qualifications (RFQ) processes, Requests for Proposals (RFP) processes and studies for other municipal jurisdictions undertaken by Stantec Staff. Generally, the information derived from official procurement processes has a higher degree of veracity.

The four most prevalent WTE technologies used to treat MSW are described below, namely, conventional combustion, gasification, plasma arc gasification, and pyrolysis. Of the four technologies mentioned, conventional combustion and gasification are the most commonly used methods of converting waste into energy. A subsection on new and emerging technologies is also provided. A database of current technology vendors (current as of March 2010) is provided in Appendix A.

It should be noted that mass burn incineration (conventional combustion) is the most well established and commercially proven thermal treatment technology. There are over 800 mass burn facilities currently in operation worldwide.

2.2.1.1 Conventional Combustion

Conventional combustion is a well-established technology developed over 100 years ago for energy generation from municipal solid waste. The first attempts to dispose of solid waste using a furnace are thought to have taken place in England in the 1870s.^[9] Since that time, vast technology improvements have been made making conventional combustion the most common WTE technology currently being used to treat MSW.

The most common conventional combustion approach is called single-stage combustion or mass burn incineration (sometimes referred to as grate-fired technology). Over 90% of WTE facilities in Europe utilize mass burn incineration technology with the largest facility treating approximately 750,000 tpy.^[10] The following paragraphs discuss the mass burn combustion process. Figure 2-4 provides a conceptual overview of a modern single-stage WTE facility.^[11]

⁹ Waste Online. 2004. History of Waste and Recycling. Accessed February 22, 2010 from <http://www.wasteonline.org.uk/resources/InformationSheets/HistoryofWaste.htm>

¹⁰ Thomas Malkow. 2004. Novel and innovative pyrolysis and gasification technologies for energy efficient and environmentally sound MSW disposal. In Waste Management 24 (2004) 53-79

¹¹ Stantec Consulting Limited. 2009. Durham/York Residual Waste Study Environmental Assessment

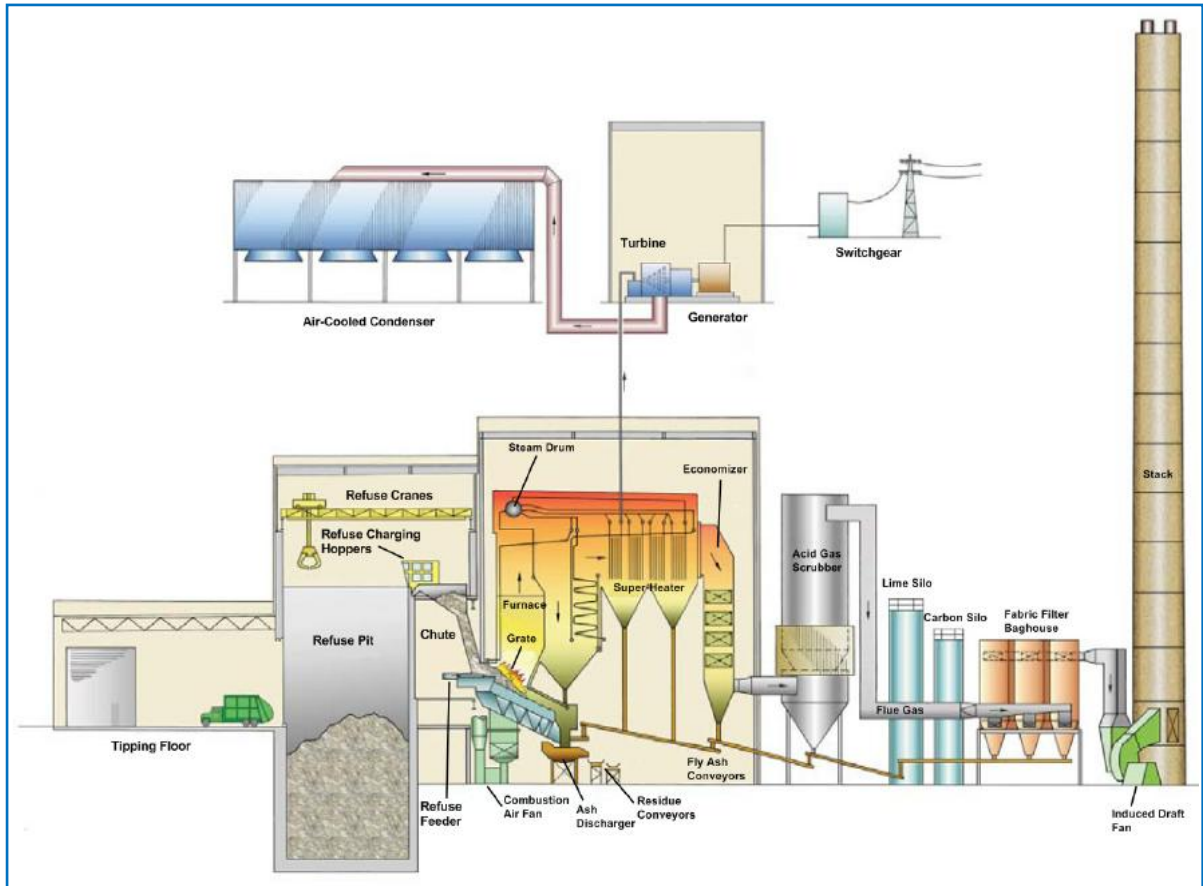
Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 2: Thermal Treatment Practices

Figure 2-4: Conceptual Overview of a Modern Single-Stage Mass Burn Incinerator



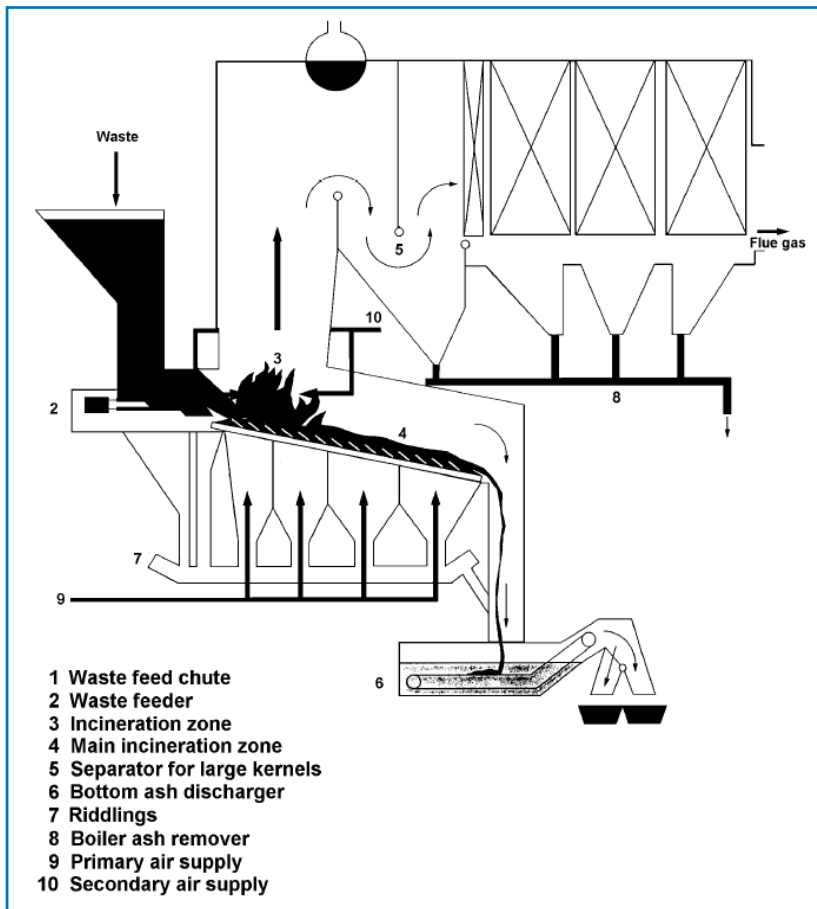
Source: Stantec Consulting Limited. 2009. Durham/York Residual Waste Study Environmental Assessment

At a mass burn facility, minimal pre-processing of MSW is required. Normally, trucks carrying refuse enter a building where they discharge their waste into a pit or bunker. From the pit, the waste is transferred into a hopper by an overhead crane. The crane is also used to remove large and non-combustible materials from the waste stream. The crane transfers the waste into a waste feed hopper which feeds the waste onto a moving grate where combustion begins.

Several stages of combustion occur in mass burn incinerators. The first step reduces the water content of the waste in preparation for burning (drying and degassing). The next step involves primary burning which oxidizes the more readily combustible material while the subsequent burning step oxidizes the fixed carbon. In single-stage combustion, waste is burned in sub-stoichiometric conditions, where sufficient oxygen is not available for complete combustion. The oxygen available is approximately 30 to 80% of the required amount for complete combustion which results in the formation of pyrolysis gases. These gases are combined with excess air and combusted in the upper

portions of the combustion chamber which allows complete oxidation to occur. Figure 2-5 shows an example of an inclined grate incinerator with a heat recovery boiler.^[12]

Figure 2-5: Example of a Grate Incinerator with a Heat Recovery Boiler



Source: German Federal Environment Agency. 2001. Draft of a German Report for the creation of a BREF-document “waste incineration”, Umweltbundesamt

Mass burn technology applications provide long residence times on the grate(s) which in turn results in good ash quality (i.e., less non-combusted carbon). Newer facilities have greatly improved energy efficiency and usually recover and export energy as either steam and/or electricity. Typical mass burn facilities have energy recovery efficiencies of 14% to 27% (assuming that the energy from combustion is being converted into electricity).^[13] Higher energy recovery efficiencies are achieved through the recovery of heat either in conjunction with or in lieu of electricity.

¹² German Federal Environment Agency. 2001. Draft of a German Report for the creation of a BREF-document “waste incineration”

¹³ AECOM Canada Ltd. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 2: Thermal Treatment Practices

Mass burn facilities can be scaled in capacity anywhere from approximately 36,500 to 365,000 tpy per operating unit.^{[14],[15]} These facilities generally consist of multiple modules or furnaces and can be expanded through addition of more units and supporting ancillary infrastructure as required. Generally it is preferred to design such facilities with multiple units allowing for individual modules to be shut down for maintenance or if there is inadequate feedstock.^[16] Multiple modules can often be accommodated on a single site with some sharing of infrastructure (e.g., share tip floor, ash management areas, stack).

The capacity of a mass burn incinerator is dependent upon the calorific value of the waste being treated. In Europe, the normal maximum size of a facility is 280,000 tpy, assuming that the waste has a calorific value of 11 MJ/kg. That said, over recent years, the trend in Europe has been to build slightly larger facilities.

Two other conventional combustion approaches are used to manage MSW, but are less common. These two other conventional approaches are modular, two stage combustion and fluidized bed combustion.

Modular, Two Stage Combustion

In modular, two-stage combustion, waste fuel is combusted in a controlled starved air environment in the first chamber. Off-gases are moved into a second chamber where they are combusted in an oxygen rich environment. The heat generated in the second stage is fed into a heat recovery boiler. Ash is generated in the first stage and is managed in a similar manner as that from moving-grate systems (mass burn incineration). Figure 2-6 provides a schematic overview of a two-stage incinerator.^[17] It should be noted that two-stage incinerators are sometimes referred to as a type of gasification technology. However, they are not true gasifiers and are therefore normally classified as a conventional combustion technology.

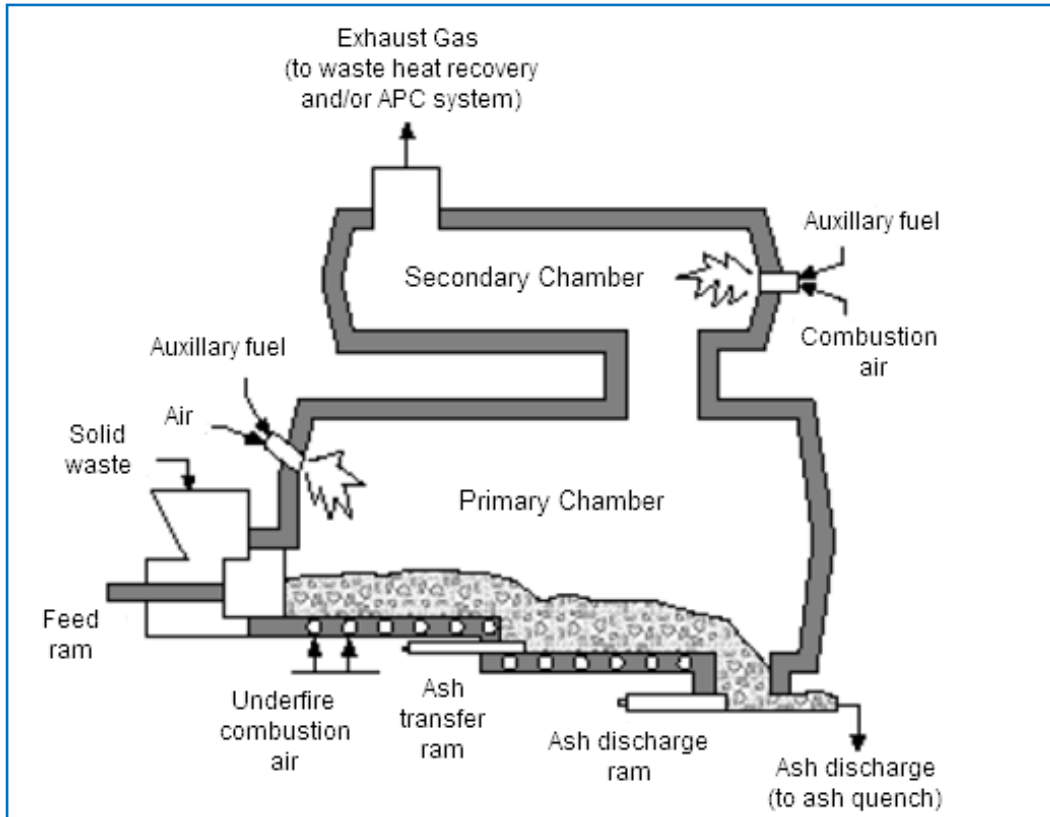
¹⁴ GENIVAR Ontario Inc. in association with Ramboll Danmark A/S, 2007. Municipal Solid Waste Thermal Treatment in Canada

¹⁵ AECOM Canada Ltd. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

¹⁶ AECOM Canada Ltd. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

¹⁷ A.J. Chandler and Associates Ltd. 2006. Review of Dioxins and Furans from Incineration In Support of a Canada-wide Standard Review

Figure 2-6: Schematic Overview of a Two-Stage Incinerator



Source: A.J. Chandler and Associates Ltd. 2006. Review of Dioxins and Furans from Incineration in Support of a Canada-wide Standard Review

Fluidized Bed Combustion

In fluidized bed combustion waste fuel is shredded, sorted and metals are separated in order to generate a more homogenous solid fuel. This fuel is then fed into a combustion chamber, in which there is a bed of inert material (usually sand) on a grate or distribution plate. The inert material is maintained in a fluid condition by air blowing upwards through it. Waste fuel is fed into or above the bed through ports located on the combustion chamber wall.

Drying and combustion of the fuel takes place within the fluidized bed, while combustion gases are retained in a combustion zone above the bed (the freeboard). The heat from combustion is recovered by devices located either in the bed or at the point at which combustion gases exit the chamber (or a combination of both). Surplus ash is removed at the bottom of the chamber and is generally managed in a similar fashion as bottom ash from a moving grate system (mass burn incineration). Figure 2-7 provides a schematic overview of a fluidized bed incinerator.^[18]

¹⁸ A.J. Chandler and Associates Ltd. 2006. Review of Dioxins and Furans from Incineration In Support of a Canada-wide Standard Review

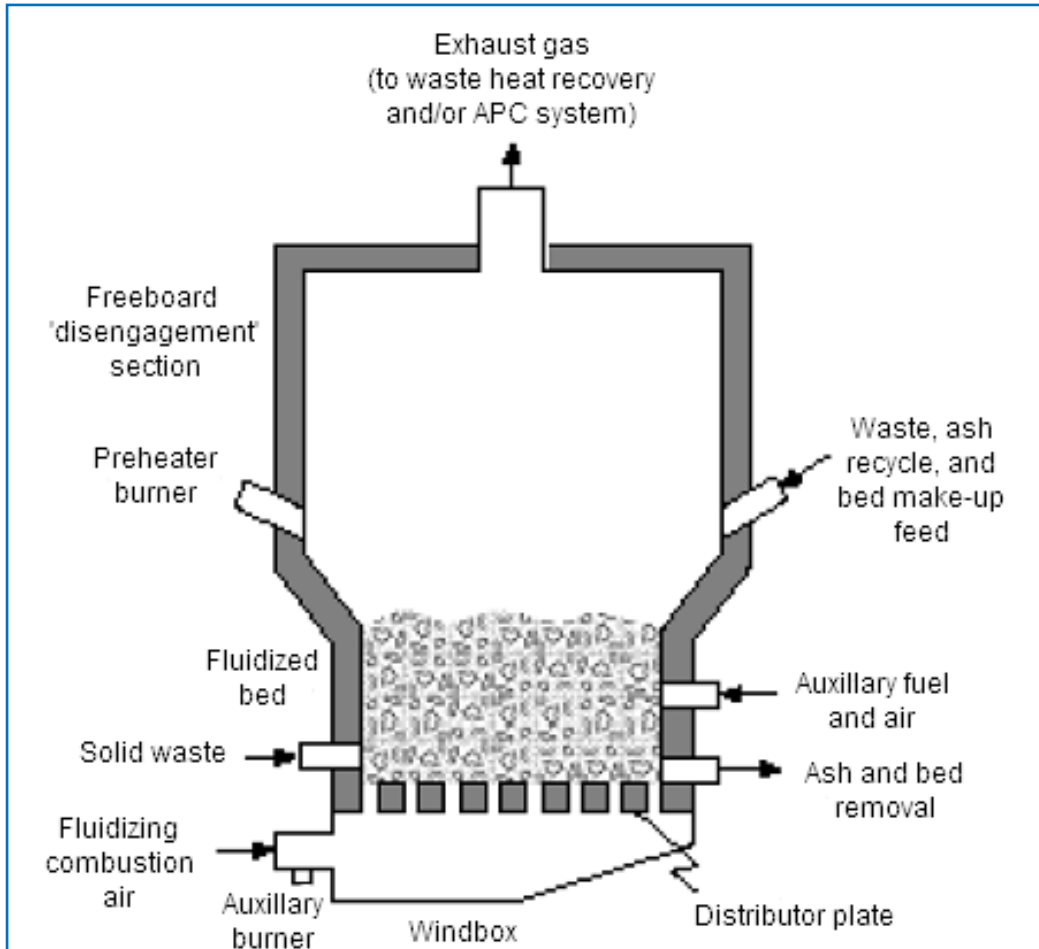
Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 2: Thermal Treatment Practices

Figure 2-7: Schematic Overview of a Fluidized Bed Incinerator



Source: A.J. Chandler and Associates Ltd. 2006. Review of Dioxins and Furans from Incineration in Support of a Canada-wide Standard Review

Both two-stage combustion and fluidized bed combustion approaches can be used to manage MSW, however, for fluidized bed applications the waste must be processed into a more homogenous feed. Both processes generally are more complex than single-stage mass burn incineration. For that reason, generally when considering conventional combustion systems in planning processes, single stage combustion systems are usually assumed.

Of the approximately 450 WTE facilities in Europe, 30 of them utilize fluidized bed technology. Most of these use a feed stock mixture of MSW, sewage sludge, industrial waste, pre-sorted organic waste, Refuse Derived Fuel (RDF) or woodchips. Very few facilities are using only MSW as feed stock because of the availability of supplemental fuels. One of the disadvantages of the fluidized bed systems is that a larger portion of fly ash is generated by the fluidized bed process (6% compared to 2% for mass burn systems) due to the particulate present in the fluidized bed itself.

Batch Combustion

In addition to mass burn, two stage and fluidized bed incineration, there are other incinerators referred to as batch waste incinerators that are capable of treating a variety of wastes including MSW. Batch waste incinerators are those that operate in a non-continuous manner (i.e., they are charged with waste prior to the initiation of the burn cycle, and the door remains closed until the ash has cooled inside the primary chamber). Batch waste incinerators tend to treat smaller amounts of waste than other conventional approaches (they are usually sized between 50 and 3,000 kg per batch) and are typically utilized in remote locations where landfill alternatives and/or wildlife concerns associated with landfills are present.

Batch waste incinerators normally utilize dual chamber controlled air technology (alike to two stage combustion but more simple). In batch incinerators, waste (which is normally pre-mixed) is charged into the primary chamber by the operator. The initial heat required to ignite the waste is supplied by a burner which shuts off once combustion becomes self-sustaining. Controlled amounts of underfire air are introduced through holes in the primary chamber and as combustion gases are created they move to the secondary chamber where combustion is completed with the air of additional over-fire air or a secondary burner.

Batch waste incinerators do not typically utilize heat recovery or air pollution control equipment but are still capable of meeting stringent emissions limits (e.g., Ontario Guideline A-7) if they are designed and operated in a proper manner.^[19]

Summary of Conventional Combustion Approaches

Conventional combustion incineration facilities that treat MSW produce unwanted emissions to air during the combustion of waste materials. Over the years, the amount of harmful byproducts produced has been greatly reduced due to the increased sophistication of the combustion and operational controls for such facilities. Emissions that are produced during combustion are reduced using Air Pollution Control (APC) systems which remove unwanted contaminants such as trace metals and various acid gases from the flue gas produced. Generally speaking there are three main types of APC systems used at conventional combustion facilities that treat MSW, namely Dry, Wet-Dry, and Wet systems. The specific aspects of these APC systems are discussed further in Section 4.2.2.

In Canada there are currently seven operational conventional combustion incinerators that treat MSW (greater than 25 tpd). These seven facilities are located in British Columbia (1), Alberta (1), Ontario (1), Quebec (3), and PEI (1).

Of these seven facilities, two are larger mass burn incinerators (L'incinérateur de la Ville de Québec, Quebec and Greater Vancouver Regional District Waste to Energy Facility, British Columbia), one is a smaller mass burn incinerator (MRC des Iles de la Madeleine, Quebec), two are defined as two-stage starved air modular incinerators (PEI Energy Systems EFW Facility, PEI and Algonquin Power Peel Energy-From-Waste Facility, Ontario), and one is defined as a three-stage incinerator (Wainwright Energy from Waste Facility, Alberta).

¹⁹ Environment Canada. 2010. Technical Document for Batch Waste Incineration

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 2: Thermal Treatment Practices

Table 2-2 provides an overview of each of these facilities.^[20]

Table 2-2: Overview of Conventional Combustion Facilities in Canada that Treat MSW

Facility Name	Thermal Treatment Units	Number of Units	Approved/ Licensed Capacity (tpd)	Air Pollution Control System
Metro Vancouver Waste to Energy Facility (1988 start-up)	Mass-burn – Martin grates	3 x 240 tonnes per day	720 (approx. 273,318 tpy)	Selective non-catalytic reduction – NH ₄ injection, spray humidifier, dry lime injection, carbon injection and fabric filter
L'incinérateur de la Ville de Québec	Mass-burn – Von Roll grates	4 x 230 tonnes per day	920 (approx. 293,300 tpy)	Spray humidifier, dry lime injection, powdered activated carbon addition, fabric filter, electrostatic precipitator
L'incinérateur de la Ville de Lévis	Primary combustion chamber with afterburner	1 x 80 tonnes per day	80 (approx. 24,768 tpy)	Spray humidifier, dry lime injection, powdered activated carbon addition, fabric filter
MRC des Iles de la Madeleine	Mass-burn – step grate	1 x 31 tonnes per day	31 (approx. 4,500 tpy)	Spray humidifier, dry lime injection, fabric filter
Algonquin Power Peel Energy-From-Waste Facility, Brampton, ON (1992 start-up)	2-stage modular Consumat units	5 x 91 tonnes per day – 5th line added in 2002	455 (permitted to operate at 118% of rated capacity) (approx. 147,700 tpy)	Spray humidifier, selective catalytic reduction, dry lime injection, powdered activated carbon addition, fabric filter
PEI Energy Systems EFW Facility, Charlottetown PEI	2-stage Starved Air Modular Consumat CS-1600 units	3x 33 tonnes per day	99 (approx. 25,623 tpy)	Spray humidifier, dry lime injection, powdered activated carbon addition, fabric filter
Wainwright Energy From Waste Facility	3-stage Starved Air Modular System	1 x 29 tonnes per day	27 (approx. 3,681 tpy)	Dry lime injection, powdered activated carbon addition, fabric filter

There are also several mass burn incineration facilities currently in the planning or development stages. One such facility is being proposed to be built by the Regions of Durham and York in Ontario. Currently, the facility is in the planning stages and awaiting Environmental Assessment approval from the Ontario Ministry of the Environment. The proposed mass burn incineration facility will be sized initially to treat 140,000 tpy (436 tpd), however the facility design will allow for future expansion up to 400,000 tpy (1290 tpd). The vendor supplying the technology for this proposed facility is Covanta.^[21]

²⁰ GENIVAR Ontario Inc. in association with Ramboll Danmark A/S, 2007. Municipal Solid Waste Thermal Treatment in Canada

²¹ Stantec Consulting Limited. 2009. Durham/York Residual Waste Study Environmental Assessment

Conventional combustion (specifically mass burn) technology is well established, with a number of established vendors that supply some or all components of the technology. Based on a recent review, over 20 vendors worldwide were found to provide some components (grate systems, boilers) or provide services for the overall Design, Build and Operation (DBO) of conventional combustion facilities.

In Europe, the four main suppliers of grates and potentially other components of mass burn incineration technology are:

- Babcock & Wilcox Vølund (Denmark)
- Fisia Babcock Environment GmbH (Germany)
- Martin GmbH (Germany)
- Von Roll Inova (Switzerland).

The same four suppliers are the primary suppliers of grates in North America as well as in Asia. In Asia, Keppel Seghers have also supplied several grate fired plants.

The majority of new WTE facilities are based on mass burn systems and the order books from the four major suppliers of the grate systems show more than 100 new lines are planned in the period from 2000 – 2011. Recent projections developed by the European Confederation of Waste to Energy Plants (CEWEP) show that for Europe, it is projected that over 470 plants (with a combined capacity of 80 million tpy) will be in operation by the end of 2011 and 550 plants (with a combined capacity of 97 million tpy) will be in operation by 2016. Currently, there are 450 conventional combustion facilities (420 mass burn, 30 fluidized bed) in operation in Europe.

Table 2-3 provides a summary of conventional combustion processes, costs, scalability and reliability.

Table 2-3: Conventional Combustion – Summary of Information

Conventional Combustion Summary
Traditional mass burn incineration is a well-established technology developed over 100 years ago for energy generation from municipal solid waste.
There are hundreds of plants in operation, including approximately 450 in Europe (420 mass burn, 30 fluidized bed), 87 in the United States and over 400 in Asia. There are seven conventional combustion facilities in Canada.
Conventional combustion facilities have reasonably good energy efficiency (up to 30% for electricity only and 60% or more for combined heat and power or just heat recovery systems) and usually export their energy as either steam and/or electricity.
The largest facility in Canada is a mass burn facility, processing approximately 300,000 tpy of waste. (Quebec City). There are several mass burn facilities in Europe that treat over 300,000 tpy.
At least 20 companies offer mass burn incineration technology or components of this technology, or services to develop such facilities in North America and elsewhere. There are four primary suppliers of the combustion (grate) systems active in the EU and North America.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 2: Thermal Treatment Practices

Conventional Combustion Summary	
Other Summary Points	
Median Reported Capital Cost	▪ \$775/annual design tonne +/- 50% (2009\$ CDN)
Median Reported Operating Cost	▪ \$65/tonne +/- 30% (2009\$ CDN)
Feedstock	▪ MSW, biomass ▪ Minimal waste preparation/pre-processing required by technology ▪ Designed to process variable waste streams
Residual to Disposal	▪ 5% (by weight) if the majority of bottom ash can be marketed for other applications ▪ Up to 20 to 25% by weight if there is no market for recovered materials from the ash (0.2 to 0.25 tonnes per input tonne) ▪ Landfill capacity consumption reduced by 90 to 95%
Potential Energy and Revenue Streams	▪ Revenue potential for: electricity, heat (steam and/or hot water), recovered recyclable metals, construction aggregate ▪ Electricity production, 0.5 to 0.6 MWh/annual tonne of MSW for older facilities ^[22] ▪ Electricity production rates of between 0.75 to 0.85 MWh/annual tonne for newer facilities
Scalability	▪ Various sizes of mass burn units; use of multiple units also possible
Reliability	▪ Numerous facilities operating worldwide with proven operational success. ▪ Less complex than other WTE approaches ▪ Scheduled and unscheduled downtime reported as <10%. ^[23]

2.2.1.2 Gasification of MSW

Gasification is the heating of organic waste (MSW) to produce a burnable gas (syngas) which is composed of a mix of primarily H₂ and CO along with smaller amounts of CH₄, N₂, H₂O and CO₂. The syngas produced can then be used off-site or on-site in a second thermal combustion stage to generate heat and/or electricity. Gasifiers are primarily designed to produce usable syngas.

There are three primary types of gasification technologies that can be used to treat waste materials, namely fixed bed, fluidized bed and high temperature gasification. Of the three types of gasification technologies, the high temperature method is the most widely employed on a commercial scale. The waste passes through a degassing duct in which the waste is heated to reduce the water content of the waste (drying and degassing) and is then fed into a gasification chamber/reactor where it is heated under suitable conditions to convert the solid fuel to syngas. Oxygen is injected into the reactor so that temperatures of over 2,000°C are reached. The amount of oxygen required is just

²² Juniper Consultancy Services. 2007. a) and b), Large Scale EFW Systems for Processing MSW; Small to Medium Scale Systems for Processing MSW

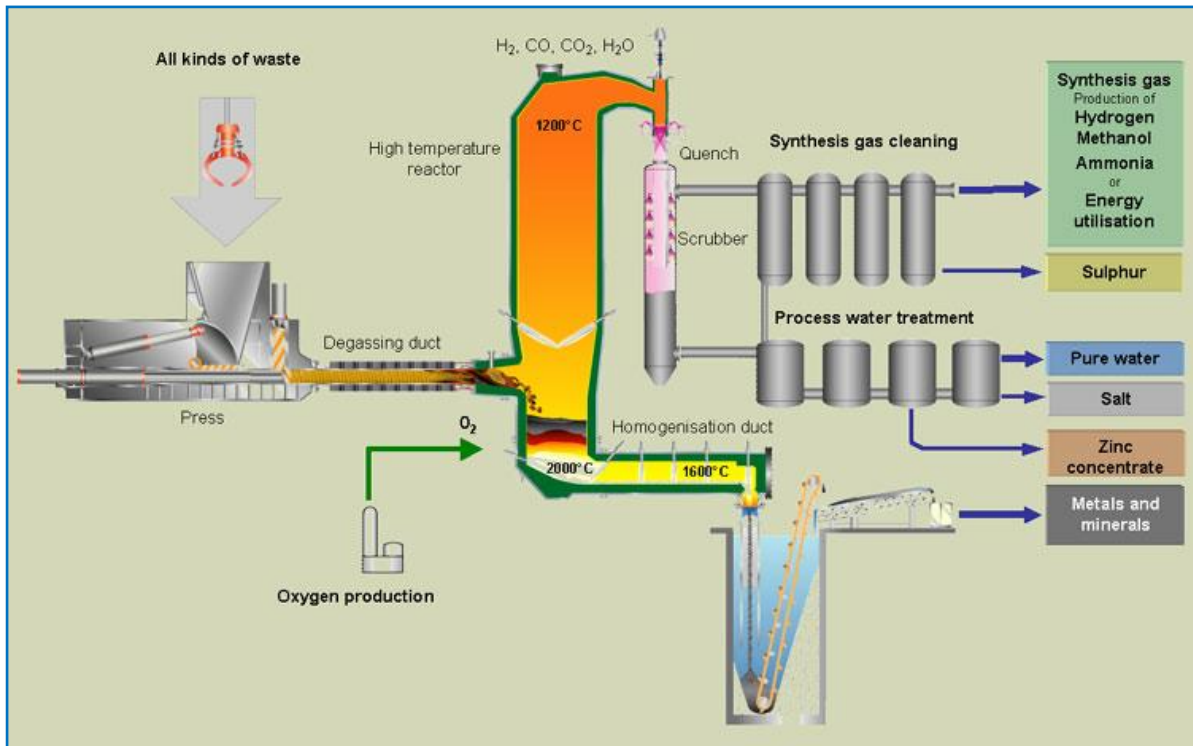
²³ AECOM Canada Ltd. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

enough to maintain the heat that is necessary for the process to proceed. The high temperature causes organic material in the MSW to dissociate into syngas. The syngas is processed to remove water vapour and other trace contaminants, so that it can be used for power generation, heating or as a chemical feedstock.

The Thermoselect technology (which is licensed to JFE Environmental Solutions Corp. of Japan and Interstate Waste Solutions of the United States) is one gasification technology used to treat MSW. As of 2009, there were six plants operating in Japan which utilize the Thermoselect technology to treat MSW.^[24]

Figure 2-8 provides a conceptual overview of a high temperature waste gasification process used to treat MSW, based on the Thermoselect process.

Figure 2-8: Conceptual Overview of a High Temperature Waste Gasifier^[25]



Source: Thermoselect. 2003. Thermoselect – High Temperature Recycling. Accessed February 3, 2010.
<http://www.thermoselect.com/index.cfm?fuseaction=Verfahrensuebersicht&m=2>

²⁴ University of California. 2009. Evaluation of Emissions from Thermal Conversion Technologies Processing Municipal Solid Waste and Biomass

²⁵ Thermoselect. 2003. Thermoselect – High Temperature Recycling. Accessed February 3, 2010
<http://www.thermoselect.com/index.cfm?fuseaction=Verfahrensuebersicht&m=2>

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 2: Thermal Treatment Practices

The following paragraph briefly illustrates the fixed bed updraft high temperature gasification process used by Nippon Steel in Japan. According to Juniper Consultancy Services, the technology utilized by Nippon Steel is the most proven waste gasification technology even though it is not well known outside of Japan.^[26] As of 2009, Nippon Steel was operating 28 facilities that utilized MSW as a feedstock.^[27]

Nippon Steel employs a high temperature gasification system, which they call a “Direct Melting System” (DMS). The process produces a ‘synthetic gas’ (syngas) that is combusted in a steam boiler, driving a steam turbine to produce electricity. The heating process begins by feeding waste into a gasification chamber/reactor. The high temperature causes organic material in the MSW to dissociate into syngas. The syngas is transferred to a combustion chamber which heats a boiler which in turn powers a turbine and produces electricity. The flue gas produced via combustion is then cleaned using a bag filter and an SCR (to reduce NO_x) before it is released into the atmosphere. The Air Pollution Control system is similar to that used for conventional combustion with the exception that no provisions for the control of acid gases have been identified in the information that is available. The ash management system is also similar to that required for conventional combustion. This system does have similarities to modular, two-stage combustion.

Figure 2-9 provides a conceptual overview of the high temperature waste gasification process employed by Nippon Steel.^[28]

²⁶ Juniper Consultancy Services Inc. 2009. Nippon Steel Gasification Process Review. Accessed February 22, 2010 from http://www.juniper.co.uk/Publications/Nippon_steel.html

²⁷ University of California. 2009. Evaluation of Emissions from Thermal Conversion Technologies Processing Municipal Solid Waste and Biomass

²⁸ Dvirka and Bartilucci Consulting Engineers. 2007. Waste Conversion Technologies: Emergence of a New Option or the Same Old Story? Presented at: Federation of New York Solid Waste Associations Solid Waste and Recycling Conference

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 2: Thermal Treatment Practices

- The facility appears to consume more energy than it produces, with a net energy output of approximately -3%.
- Plant availability: 5,300-5,700 hours/year (approximately 65%). Scheduled and unscheduled downtime was required due to change of refractory, leakages in the gasifier.

JFE indicated in the site tour that they did not intend to build any further gasifiers with the Thermoselect technology in Japan.

Outside of Japan, gasification is only used at a few facilities to treat MSW. This is primarily due to operational issues that arise due to the heterogeneous nature of MSW as the gasification process generally requires a fairly homogenous feedstock. In addition, gasification tends to have much higher range of operating and capital costs in comparison with conventional combustion facilities, given the requirement for waste pre-processing and the added complexity of the technology. Gasification also tends to have higher net costs, given that generally less energy (and thus less revenue) is recovered from the waste stream. ^[29]

In Europe, there are currently no commercially operating gasification facilities that treat MSW as the technology is considered too expensive and unproven. The only larger scale commercial gasifier using MSW as feedstock was a Thermoselect gasification plant that was operated in Karlsruhe, Germany for a few years, but it was shut down in 2004 due to technical and financial difficulties. ^[30] There are several (6 – 7) new gasification facilities operating at a commercial scale in Japan which have been constructed within the past 10 years. The use of gasification in Japan is partly driven by the regulatory environment which favours high temperature treatment (slagging) of the bottom ash/char due to the presence of low levels of dioxins. The Japanese regulatory approach is somewhat different from other jurisdictions as it regulates net dioxin emissions to the environment from all sources (air, waste water, ash). Such an approach has not been applied in other jurisdictions for WTE (e.g., the EU) as other regulatory approaches related to ash and effluent management have been used to minimize health and environmental impacts as discussed in later sections of this report.

Gasification facilities require APC systems to reduce unwanted emissions to air, although the APC approach will vary based on how the syngas is processed as discussed below. Gasification systems and mass burn systems are not directly comparable as the point in the process where combustion takes place differs, as does the APC approach. Although, gasification systems generally appear to have (or report to have) somewhat lower stack emissions than mass burn WTE plants, these results are based on testing from pilot-scale facilities, not actual commercial-scale operations. ^[31] Stack emissions test results from the Japanese facilities discussed above were not available when this report was being completed.

There are two key differences between APC systems for gasification systems and conventional mass burn combustion: first, some gasification approaches focus on cleaning of the syngas prior to

²⁹ Fichtner Consulting Engineers. 2004. The Viability of Advanced Thermal Treatment of MSW in the UK. Published by ESTET, London

³⁰ AECOM Canada Ltd. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

³¹ RPS-MCOS Ltd. 2005. Feasibility Study of Thermal Waste Treatment/Recovery Options in the Limerick/Clare/Kerry Region

combustion, so that emissions control is based on the control of syngas quality; second, based on the composition of the syngas, it may be directly combusted and have some form of more conventional APC system, however these systems may be sized smaller and/or may not require certain APC components that would normally be necessary for a conventional approach. Table 2-4 provides a summary of gasification processes, costs, scalability and reliability.

It should be noted that the available costing information for gasification technologies is generally provided through informal processes and not on the basis of any contractual commitments to the parties involved. Therefore, it is not clear that reported capital costs address all capital and construction cost elements, nor is it clear that reported operating costs address all real costs associated with such facilities. The cost for each facility will vary on a site-by-site basis.

Table 2-4: Gasification – Summary of Information

Gasification Summary	
Gasification combusts fuel to create syngas.	
The technology has been in use for over a century, but only recently has MSW been used as a feedstock.	
At least 42 companies offer gasification technologies or components of this technology that are capable (or claim to be capable) of treating mixed MSW in North America and elsewhere.	
The earliest example of this technology being used for MSW was in 1991 in Taiwan.	
Other Summary Points	
Median Reported Capital Cost	<ul style="list-style-type: none"> ▪ \$850/annual design tonne +/- 40% (2009\$ CDN)
Median Reported Operating Cost	<ul style="list-style-type: none"> ▪ \$65/tonne +/- 45% (2009\$ CDN) (this reported cost by vendors seems well below the range of expected operating costs based on performance of gasification in the EU and Japan)
Feedstock	<ul style="list-style-type: none"> ▪ Automobile shredder residue (ASR), biomass, black liquor, coal, hospital waste, MSW, organic waste streams, plastics, PVC, refinery residues, sludge, tires ▪ Waste preparation/pre-processing required by technology ▪ Difficulties in accepting variable (heterogeneous) waste streams
Residual to Disposal	<ul style="list-style-type: none"> ▪ <1 % if bottom ash can be marketed for other applications ▪ 10 to 20% if it is not marketable (0.1 to 0.2 tonnes of residue per 1 tonne of input waste)^[32] ▪ Landfill capacity consumption reduced by 90 to 95%
Potential Energy and Revenue Streams	<ul style="list-style-type: none"> ▪ Revenue potential for: electricity, syngas, aggregate recovered from ash ▪ Electricity production, 0.4 to 0.8 MWh/annual tonne of MSW^[33]
Scalability	<ul style="list-style-type: none"> ▪ Usually built with a fixed capacity; modular ▪ Individual modules range in size from approximately 40,000 to 100,000 tpy^[34]

³² Juniper, 2007 a) and b), Large Scale EFW Systems for Processing MSW; Small to Medium Scale Systems for Processing MSW

³³ Juniper, 2007 a) and b), Large Scale EFW Systems for Processing MSW; Small to Medium Scale Systems for Processing MSW

³⁴ AECOM Canada Ltd. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 2: Thermal Treatment Practices

Gasification Summary

Reliability	<ul style="list-style-type: none">▪ At least seven plants in operation in Japan at a large scale with over two years of operating experience^[35].▪ Limited data available in other jurisdictions to assess operational success with MSW feedstock in regards to technical reliability▪ Complex operation▪ Scheduled and unscheduled downtime reported as approximately 20%^[36], However other reports indicate potential for up to 45% downtime.
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2.2.1.3 Plasma Arc Gasification

Plasma arc gasification uses an electric current that passes through a gas (air) to create plasma which gasifies waste into simple molecules. Plasma is a collection of free-moving electrons and ions that is formed by applying a large voltage across a gas volume at reduced or atmospheric pressure. The high voltage and a low gas pressure, causes electrons in the gas molecules to break away and flow towards the positive side of the applied voltage. When losing one or more electrons, the gas molecules become positively charged ions that transport an electric current and generate heat.

When plasma gas passes over waste, it causes rapid decomposition of the waste into syngas. The extreme heat causes the inorganic portion of the waste to become a liquefied slag. The slag is cooled and forms a vitrified solid upon exiting the reaction chamber. This substance is a potentially inert glassy solid. The syngas is generally combusted in a second stage in order to produce heat and electricity for use by local markets. In some cases, alternative use of the syngas as an input to industrial processes has been proposed.

Currently, plasma arc gasification is not commercially proven to treat MSW. The primary reason appears to be the high capital and operational costs for such facilities. The wear on the plasma chamber is very high and to keep the process operating redundant plasma chambers are needed.

Plasma technology for MSW management has been discussed in Europe since the late 1980s but full scale facilities for MSW have not yet been implemented. At some Japanese facilities, a back-end plasma component has been added to vitrify the bottom ash produced from conventional mass burn combustion facilities. Ramboll recently visited the plant in Shinminto, Japan, where MSW combustion is undertaken by a traditional grate fired WTE facility with a back-end ash melter. The downstream ash melter is operated by JFE and consists of two, 36 tonne per day units. Melting of the ash is undertaken by a plasma arc, operating at approximately 2,000 degrees centigrade. The melted ash is water quenched. The total amount of vitrified residues represents 50% by weight of the incoming ash. Approximately 1/3 of the material is used for construction purposes and the other 2/3 is used as landfill cover. The process consumes significant energy, generally producing net energy of only

³⁵ AECOM Canada Ltd. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

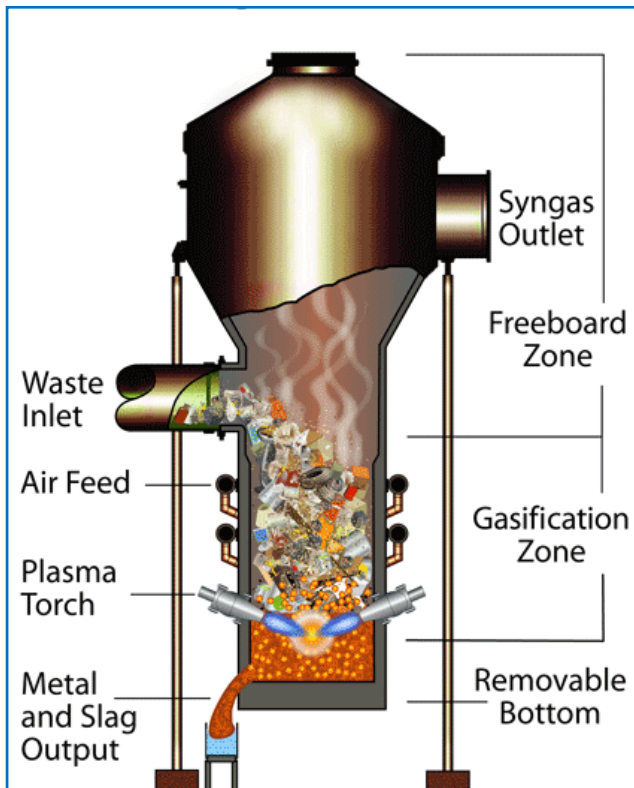
³⁶ AECOM Canada Ltd. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

100 kW per tonne of incoming ash, due to the limited fraction of remaining carbon left in the ash which limits the production of any syngas and thus limits energy production. Note: most ash management processes are net consumers of energy. Plasma chambers in operation in Japan experience a three-month cycle where the chamber has to be taken out of operation for repair every three months mainly to change the refractory lining.

There are no large scale commercial plants in operation in North America or Europe but there are a number of plasma arc systems that are being tested or proposed to treat MSW. Two technologies which are currently being tested in Canada are the Alter NRG process and the Plasco process. Both are discussed further below.

In the Alter NRG process, a plasma torch heats the feedstock to high temperatures in the presence of controlled amounts of steam, air and oxygen. The waste reacts with these constituents to produce syngas and slag. Figure 2-10 provides a conceptual overview of the Alter NRG plasma gasification process.^[37]

Figure 2-10: Conceptual Overview of Alter NRG Plasma Gasification Unit



Source: Westinghouse Plasma Corporation. 2007. Westinghouse Plasma Corp. – Technology and Solutions – PGVR. Accessed February 3, 2010. http://www.westinghouse-plasma.com/technology_solutions/pgvr.php

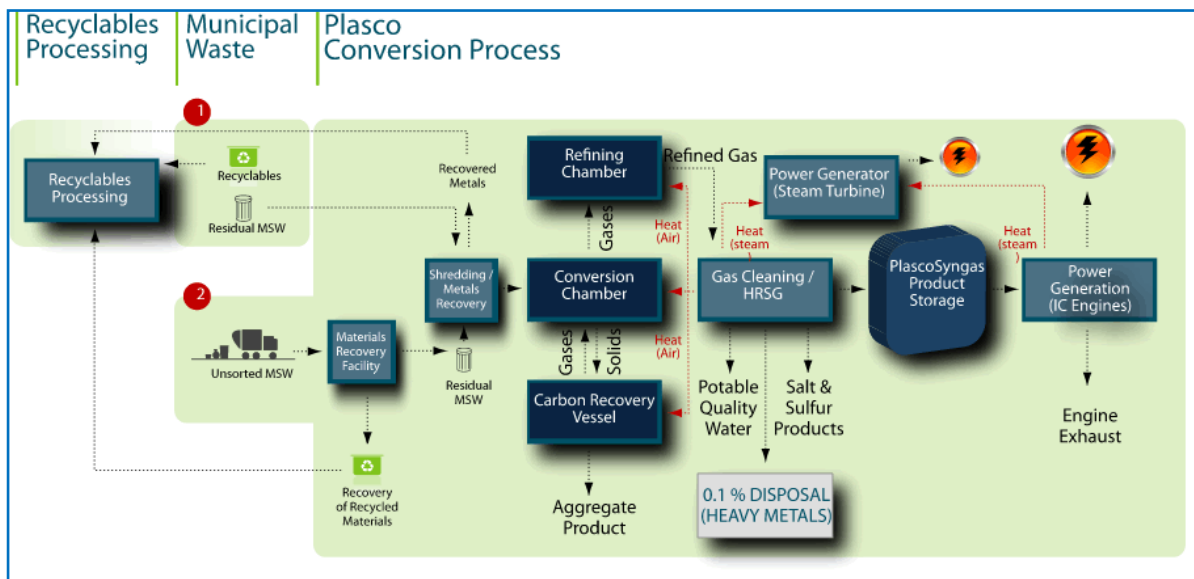
³⁷ Westinghouse Plasma Corporation. 2007. Westinghouse Plasma Corp. – Technology and Solutions – PGVR. Accessed February 3, 2010. http://www.westinghouse-plasma.com/technology_solutions/pgvr.php

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 2: Thermal Treatment Practices

Plasco Energy Corp. (Plasco) has also developed a plasma arc gasification technology capable of treating MSW. Figure 2-11 presents a conceptual overview of the Plasco process.^[38]

Figure 2-11: Conceptual Overview of the Plasco Process



NOTE:

HRSG stands for heat recovery steam generator

Source: Plasco Energy Group. Accessed February 22, 2010

http://www.plascoenergygroup.com/images/Plasco_conversion_process_big.gif

In April 2006 Plasco entered into an agreement with the City of Ottawa to develop a demonstration facility on City-owned property next to the City's Trail Road Landfill. Construction began in June 2007, and the first waste was received at the facility in January 2008. The plant is permitted to process 85 tonnes per day of solid waste provided by the City using Plasco's conversion technology, and Plasco claims that the process would produce 1,150 kWh of power per tonne of waste when fully operational.

In the first year of operations (2008), the plant processed approximately 2,000 tonnes of MSW (6% of the permitted annual quantity of MSW), operating for 890 hours^[39] or approximately 37 days (10% plant availability). Commissioning has indicated the need for improvements to the front end of the plant, including pre-processing of the curbside MSW to ensure that the waste received is suitable for the conversion chamber. The 2009 operating report for the Ottawa plant was not available as of the end of March 2010. The demonstration plant is currently permitted to operate until January 21, 2011. Final documentation for the demonstration plant will include stack test emissions results that are not yet available.

³⁸ Plasco Energy Group. Accessed February 22, 2010. http://www.plascoenergygroup.com/images/Plasco_conversion_process_big.gif

³⁹ Plasco Energy Group. 2010. *Environmental Performance*. Accessed February 10, 2010
http://www.plascoenergygroup.com/?Environmental_Performance

In the Plasco process, the syngas produced in the primary conversion chamber is refined and cleaned. No emissions to air are generated during the creation of Syngas from MSW. The emissions to air from the process are associated with the combustion of the Syngas in gas engines to produce electricity. These emissions must meet requirements in the operating permit that are more stringent than those set out in Ontario guidelines for PM, Organic matter, HCl, NO_x, mercury, cadmium, lead and dioxins/furans.

Table 2-5 provides a summary of the plasma arc gasification process, costs, scalability and reliability.

Table 2-5: Plasma Arc Gasification – Summary of Information

Plasma Arc Gasification Summary	
Plasma gasification uses an electric current that passes through a gas to create plasma.	
Plasma arc is not a new technology; it has industrial applications and has been used for treating hazardous waste.	
The earliest facility found to use plasma arc gasification was a test facility which operated from 1987 – 1988.	
The largest facility currently operating in the world is located in Japan (Eco-Valley Utashinai Plant) and processes over 90,000 tpy of MSW and automobile shredder residue (ASR).	
24 companies supplying Plasma Arc gasification technologies and/or services have been identified that indicate use of MSW as a portion of their feedstock.	
Other Summary Points	
Median Reported Capital Cost	<ul style="list-style-type: none"> \$1,300/annual design tonne +/- 40% (2009\$ CDN)
Median Reported Operating Cost	<ul style="list-style-type: none"> \$120/tonne +/- 50% (2009\$ CDN)
Feedstock	<ul style="list-style-type: none"> MSW, ASR, hazardous waste, hospital waste, organic waste streams, shipboard waste, tires Waste preparation/pre-processing required by technology Difficulties in accepting variable waste streams
Residual to Disposal	<ul style="list-style-type: none"> Estimated at >1 to 10% (0.1 tonne of residue per 1 tonne of input waste), varying due to the nature of the waste and efficiency of the conversion process.^[40] Inert Slag, APC residue Landfill capacity consumption reduced by up to 99%
Potential Energy and Revenue Streams	<ul style="list-style-type: none"> Revenue potential for: electricity, syngas, aggregate substitute Electricity production, 0.3 to 0.6 MWh/annual tonne of MSW^[41] NOTE: Plasma arc facilities tend to consume more energy to operate than other types of facilities
Scalability	<ul style="list-style-type: none"> Modular facilities; multiple modules can be accommodated on a single site with some sharing of infrastructure.

⁴⁰ Juniper, 2007 a) and b), Large Scale EFW Systems for Processing MSW; Small to Medium Scale Systems for Processing MSW

⁴¹ Juniper, 2007 a) and b), Large Scale EFW Systems for Processing MSW; Small to Medium Scale Systems for Processing MSW

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 2: Thermal Treatment Practices

Plasma Arc Gasification Summary

Reliability	<ul style="list-style-type: none">▪ Limited data available to assess operational success with MSW feedstock in regards to technical reliability▪ Eco-Valley Utashinai Plant, Japan processes over 90,000 tpy of material but feedstock is not 100% MSW▪ Only two plants (Japan) with 2 or more years of operations▪ Canadian facility (Plasco in Ottawa) has not been in regular (24/7) operation as of early 2010▪ Complex Operation, scheduled and unscheduled downtime, unknown^[42].
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2.2.1.4 Pyrolysis

The concept of pyrolysis of MSW gained popularity in the 1960s as it was assumed that since MSW is typically about 60% organic matter, it would be well suited to pyrolytic treatment. By the mid-1970s studies in Europe and the United States concerning the pyrolysis of MSW were completed, some of these studies involved the construction and operation of demonstration plants. By the late 1970s, however, both technical and economic difficulties surrounding the pyrolysis of MSW arose which resulted in the lowering of interest and expectations for the technology. Since that time, the pyrolysis of MSW has been investigated but continues to face technical limitations.

Pyrolysis is the thermal decomposition of feedstock at a range of temperatures in the absence of oxygen. The end product is a mixture of solids (char), liquids (oxygenated oils), and syngas (consisting of CO₂, CO, CH₄, H₂). The pyrolytic oils and syngas can be used directly as boiler fuel or refined for higher quality uses such as engine fuels, chemicals, adhesives, and other products. The solid residue is a combination of non-combustible inorganic materials and carbon.

Pyrolysis requires thermal energy that is usually applied indirectly by thermal conduction through the walls of a containment reactor since air or oxygen is not intentionally introduced or used in the reaction. The transfer of heat from the reactor walls occurs by filling the reactor with inert gas which also provides a transport medium for the removal of gaseous products.

The composition of the pyrolytic product can be modified by the temperature, speed of process, and rate of heat transfer. Liquid products (pyrolytic oils) are produced by lower pyrolysis temperatures while syngas is produced by higher pyrolysis temperatures. The syngas produced can be combusted in a separate reaction chamber to produce thermal energy which can then be used to produce steam for electricity production.

A full scale (100,000 tpy) facility began operating in 1997 in Fürth, Germany. Modifications to the facility were made between 1997 and 1998 but in August, 1998 the plant was closed following an explosion resulting from a waste 'plug' causing over pressurization of the reaction chamber. At

⁴² AECOM Canada Ltd. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

present there are no large scale pyrolysis facilities are in operation in Europe. However, a smaller facility has been in operation in Burgau in the Eastern part of Europe.

There were a total of six pyrolysis plants in operation in Japan as of the end of 2007 based on the information available as of March 2010. Information on the current (2010) status of these facilities was not available as of the date that this report was prepared. A new facility was being built in Hamamatsu (2007/2008) using this technology, which is intended to process approximately 450 tpd. Ramboll recently visited a similar pyrolysis facility located at the Toyohashi Waste Treatment Recovery and Resource Center, Toyohashi Japan. Information obtained during the facility visit includes the following:

- The facility consists of two 200-tpd units that process MSW (or approximately 120,000 tpy based on availability).
- The facility was commissioned in 2002.
- The recovery and resource center also has a grate-fired mass burn facility to process MSW.
- The overall capital cost for the pyrolysis plant was approximately \$165 million USD (1998\$).
- The facility is similar to the plant in Fürth with modifications.
- The process involves low temperature pyrolysis (400°C) followed by a high temperature secondary combustion/residual vitrification stage.
- Aluminum and iron are removed after the pyrolysis drum.
- The APC train includes: quenching, baghouse for PM removal, SCR for NO_x, and flue gas recirculation.
- Incoming waste is shredded to 15x15 cm and has an average heat value of 9.2 MJ/kg.
- Residues: bottom ash 12.4%, with recovery of iron and aluminum.
- Energy production: yearly production 41 GWh electricity, with 90% used for internal consumption and pre-treatment. Only 4.46 GWh is sold.
- Heat produced is used to heat a public swimming pool.
- Availability: approximately 6,900 hours per year for line 1 and 7,400 hours per year for line 2 or over 80%. Scheduled and unscheduled downtime is required to repair the refractory lining of the reactor.
- Overall, the operators find the grate fired plant more reliable and flexible with higher availability in comparison with the pyrolysis plant.

Due to the pre-treatment of waste and the fuel burned in the high temperature chamber, the electrical output from the pyrolysis process is almost balanced with the internal energy consumption.

Pyrolysis generally takes place at lower temperatures than used for gasification which results in less volatilization of carbon and certain other pollutants, such as heavy metals and dioxin precursors. The relatively low temperatures allow for better metal recovery before the residual pyrolysis products enter the high temperature chamber where they are vitrified.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

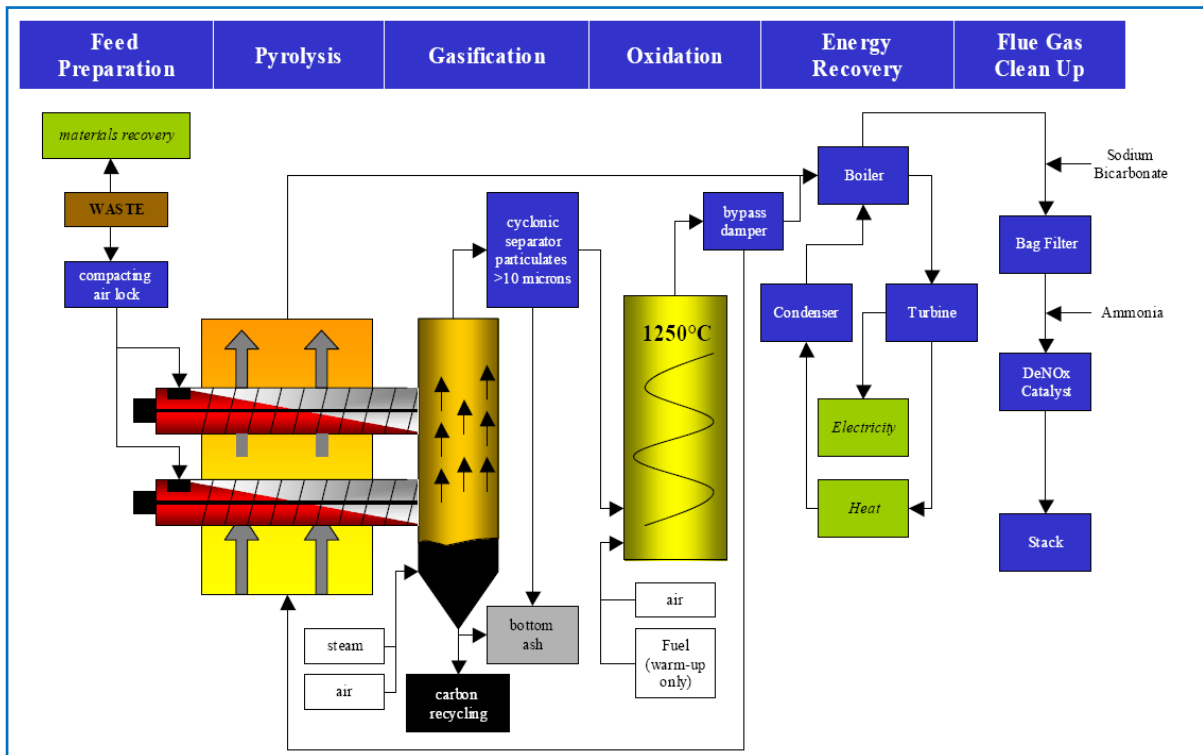
Section 2: Thermal Treatment Practices

Issues identified in relation to the pyrolysis process include:

- Low energy outputs
- The requirement for a properly sealed reaction chamber for safe operation. The pyrolysis process is highly sensitive to the presence of air. Accidental incursions of air can result in process upsets and increase the risk of explosive reactions.
- The requirement for pre-treatment of the MSW.

The following figure (Figure 2-12) presents a schematic overview of the Compact Power pyrolysis technology as developed by Compact Power Ltd. In the Compact Power process, sorted MSW is conveyed by a screw through the heated tubes for pyrolysis, followed by gas combustion in a cyclone where energy is captured to produce steam and then electricity. It should be noted that the Compact Power technology utilizes a gasification step following pyrolysis – this does not necessarily occur in all pyrolysis based WTE facilities.^[43]

Figure 2-12: Schematic Overview of the Compact Power Pyrolysis Process



Source: Thomas Malkow. 2004. Novel and innovative pyrolysis and gasification technologies for energy efficient and environmentally sound MSW disposal. In Waste Management 24 (2004) 53-79

⁴³ Thomas Malkow. 2004. Novel and innovative pyrolysis and gasification technologies for energy efficient and environmentally sound MSW disposal. In Waste Management 24 (2004) 53-79

Table 2-6 provides a general summary of pyrolysis process, costs, scalability and reliability. This cost data is less reliable than the costs presented in this report for other technologies since:

- It is unclear if the reported capital costs address all capital and construction cost elements.
- It is not clear that reported operating costs address all costs associated with such facilities.
- It was also noted that the values were consistently reported to be lower than other similar WTE technologies, but without supporting rationale for these differences.

Table 2-6: Pyrolysis – Summary of Information

Pyrolysis Summary	
Pyrolysis is the thermal decomposition of feedstock at high temperatures in the absence of oxygen.	
The longest operating pyrolysis facility is located in Burgau, Germany and has been operating since 1987.	
The largest facility (located in Japan) processes approximately 150,000 tpy of SRF.	
Over 20 companies market pyrolysis technologies or approaches for treating MSW.	
Other Summary Points	
Median Reported Capital Cost	▪ No reliable data
Median Reported Operating Cost	▪ No reliable data
Feedstock	<ul style="list-style-type: none"> ▪ Biomass, automotive shredder residue, coal, hospital waste, MSW, plastics, polyvinyl chloride, sludge, tires, wastewater ▪ Waste preparation/pre-processing required by technology ▪ Difficulties in accepting variable waste streams
Residual to Disposal	<ul style="list-style-type: none"> ▪ If treated, residues reduced to 0.1 to 0.3 tonnes per input tonne ▪ >30%, if residue not treated ▪ Landfill capacity consumption reduced by up to 90%
Potential Energy and Revenue Streams	<ul style="list-style-type: none"> ▪ Revenue potential for: electricity, syngas, pyrolysis oil ▪ Electricity production, 0.5 to 0.8 MWh/annual tonne of MSW^[44]

The flue gas from the combustion of the pyrolysis gas must be treated in an APC system of one of the types presented in Section 2.2.4.2 of this report. No fundamental differences have been identified to-date between flue gas from conventional grate fired plants and pyrolysis plants.

2.2.2 Emerging Combustion and Thermal Treatment Technologies

There is a great deal of flux in the thermal treatment marketplace, with regard to new and emerging technologies. However, many of the emerging technologies have yet to be proven and the financial capacity of many of the new technology vendors is limited.

With more proven technologies such as mass burn, the evolution of technology has focused on improving combustion and emissions performance through design adjustments, such as new grate

⁴⁴ Juniper, 2007 a) and b), Large Scale EFW Systems for Processing MSW; Small to Medium Scale Systems for Processing MSW

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 2: Thermal Treatment Practices

design and improved combustion air management systems. Significant achievements associated with more conventional technologies include low-NO_x burners, improved efficiency, heat exchangers, waste heat recovery systems, and newly developed equipment for wet scrubbing and activated carbon absorption.

The following is a selected list of some emerging combustion and thermal treatment technologies. While there are other emerging technologies, the following represents technologies that are in development (preliminary development, test facilities or commercial scale proposals) in North America. The information has been made available from technology vendors and generally is yet to be verified by any independent parties.

2.2.2.1 Gasplasma

The gasplasma process is used by Advanced Plasma Power, a United Kingdom-based company. They currently have one small-scale, demonstration plant in operation. The gasplasma process uses waste feedstock to produce clean hydrogen-rich syngas and Plasmarok™, a vitrified recyclate, which reportedly can be used as a building replacement or replacement aggregate.

The gasplasma process is designed for post-diversion materials (i.e., those materials that cannot be recycled or composted). Although it can operate with a variety of feedstock, it operates most efficiently when treating a prepared SRF. Advanced Plasma Power utilizes three different technologies in their process: fluidized bed gasification, plasma arc treatment and a power island. The gasifier operates at a temperature of approximately 900°C. At this temperature, the material is thermally broken down into syngas. The plasma arc treatment “cracks” the dirty syngas coming out of the gasifier. The cracking process breaks the molecular structure of the syngas and reforms it into a simpler structure, thereby producing a hydrogen-rich fuel gas. The hydrogen-rich fuel gas is cooled and further cleaned before being fed into the gas engines at the power island. It is claimed that the electrical generating efficiency reaches 35 – 40%.

The fluidized bed gasifier used in the gasplasma process produces char and ash (approximately 10 – 15% of the feedstock), this material is recovered in Plasmarok™. Plasmarok™ is stated as being an environmentally stable material that can be re-used as a building aggregate (in the UK). The vendor claims Plasmarok™ significantly reduces the amount of residue requiring landfilling; from 60,000 tonnes of SRF, 450 tonnes of activated carbon from the gas scrubbers requires landfilling (over 99% reduction).^[45]

2.2.2.2 Thermal Cracking Technology (Fast Pyrolysis)

Graveson Energy Management (GEM) uses traditional petrochemical industry technology to convert MSW into clean synthetic gas. A GEM facility employing thermal cracking technology has been operating in Romsey, England since 1998. It can process up to 1,680 tonnes per day of RDF that has

⁴⁵ Advanced Plasma Power. 2010. *What is Gasplasma – The Process*. Accessed February 10, 2010
<http://www.advancedplasmapower.com/index.php?action=PublicTheProcessDisplay>

been ground to less than 2 mm particle size and dried to 5% moisture. Thermal cracking is also described as “fast pyrolysis” as it involves rapid heating of the waste fuel in the absence of oxygen.

In thermal cracking, prepared waste material is fed into the oxygen-free chamber. The chamber has stainless steel walls that are heated to 850°C. The waste material is instantly heated and thermally cracks to syngas in a matter of seconds. Syngas entering the Gas Filtration system is further filtered to remove finer particles and is cooled rapidly from 1,500°C to less than 400°C to prevent the formation of dioxins and furans. A small portion of the clean syngas is used to heat the GEM Converter, which reduces the need for fossil fuels. The remainder of the syngas can be used in boilers, engines, or turbines for generation into energy. Mineral solids are produced as a residual, typically in the amount of 8 – 10% for domestic waste.^[46]

2.2.2.3 Thermal Oxidation

Zeros Technology Holdings uses an Energy Recycling Oxidation System that can reportedly dispose of all classifications of waste. Zeros claims no emissions are produced in the process and other effluents can be sold as products or reintroduced into the system, however to our knowledge, these claims have not been supported by independent verification. The system is closed and uses pure oxygen for the oxidation process, as opposed to ambient air. The oxidation process used by this technology was originally developed for oil spill remediation. Several projects are in various stages of development, however there is currently no Zeros facility in operation.

Zeros combines six different technologies in their process: rotary kiln; gasification (Oxy-Fuel Technology); Rankine Cycle Technology; Fischer-Tropsch Fuels Technology; Gas Capture Technology; and Clean Water Technology. The gasification-oxidation process is a two stage process using limited oxygen and high temperature. The system gasifies the fuel source to produce primarily Carbon Monoxide and Hydrogen. This synthetic gas forms the building blocks for the transformation to liquid fuels such as diesel using the Fischer-Tropsch technology.^[47]

2.2.2.4 Waste-to-Fuels

Approaches to transform waste into fuels are generally based on the concept that rather than using the syngas produced through gasification as a direct energy source, the syngas can be used as a feedstock to generate various liquid fuels that could then be used off-site.

Enerkem intends to construct the world’s first facility intended to produce biofuels from MSW. Construction of the Edmonton facility is set to begin in April 2010 and operations are currently planned to begin in mid-2011.^[48] Enerkem indicates Alberta will reduce its carbon dioxide footprint by more than six million tons over a 25 year period, while producing 36 million liters of ethanol annually through the use of this facility.

⁴⁶ GEM Canada Waste to Energy Corp. 2009. *Process Description and Gas Production*. Accessed February 10, 2010. <http://www.gemcanadawaste.com/53257.html>

⁴⁷ Zeroes Technology. 2008. Accessed May 10, 2010 <http://www.zerosinfo.com/technology.php>

⁴⁸ Enerkem. 2010. Edmonton Biofuels Project Status and Schedule. http://www.edmontonbiofuels.ca/status.htm?yams_lang=en

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 2: Thermal Treatment Practices

Enerkem converts urban biomass, agricultural residues and/or forest residues into biofuels by means of a four step process:

1. Pre-treatment of the feedstock which involves drying, sorting and shredding of the materials.
2. Feedstock is fed into the gasifier. The bubbling fluidized bed gasifier converts the residues into synthetic gas and operates at a temperature of approximately 700°C.
3. Synthetic gas cleaning and conditioning, which includes the cyclonic removal of inerts, secondary carbon/tar conversion, heat recovery units, and reinjection of tar/fines into the reactor.
4. Conversion of syngas into biofuels.

Enerkem intends to produce approximately 360 litres of ethanol from 1 tonne of waste (dry base).^[49]

Changing World Technologies employs a Thermal Conversion Process which converts waste into oil. They state: "The Thermal Conversion Process, or TCP, mimics the earth's natural geothermal process by using water, heat and pressure to transform organic and inorganic wastes into oils, gases, carbons, metals and ash. Even heavy metals are transformed into harmless oxides". Changing World Technologies does not have a commercial facility at this time; however they do have a test centre in Philadelphia, PA.^[50]

2.2.3 Summary of Major Thermal Treatment Technologies

Table 2-7 presents an overview of the four major types of WTE technologies used worldwide and a number of their key characteristics.

Table 2-7: Overview of the Four Major Types of WTE Technologies Used Worldwide

Characteristic	Conventional Combustion			Gasification	Plasma Gasification	Pyrolysis
	Mass Burn	Fluidized Bed	Two-Stage			
Applicable to unprocessed MSW, with variable composition	YES	NO	YES	NO	NO	NO
Commercially Proven System, with relatively simple operation and high degree of reliability	YES	YES	YES	Commercially proven to limited degree, more complex than combustion and less reliable, very costly	NO	NO
Reasonably Reliable set of Performance Data	YES	NO	YES	Limited data. Operational problems have been documented.	Limited data. Operational problems have been documented.	Limited data. Operational problems have been documented.

⁴⁹ Enerkem. 2010. *Technology Overview*. Accessed February 10, 2010
<http://www.enerkem.com/index.php?module=CMS&id=6&newlang=eng>

⁵⁰ Changing World Technologies. 2010. *What Solutions Does CWT Offer? What is Thermal Conversion Process (TCP)?*. Accessed February 10, 2010. <http://www.changingworldtech.com/what/index.asp>

3 POTENTIAL DISCHARGES FROM THERMAL TREATMENT

3.1 Air Emissions

3.1.1 Overview of Potential Emission Constituents

The following table (Table 3-1) illustrates the main sources of air emissions from WTE facilities.^{[51] [52]}

Table 3-1: Main Sources of Key Substances of Concern Released from WTE Facilities

Substances	Comments and Main Sources
Particulate matter (including PM ₁₀ , PM _{2.5} and ultrafine (nanoparticles))	Present in flue gas as fine ash from the incineration process entrained in the flue gas. There can also be fugitive releases of dust from waste storage areas and ash management if good operational controls are not in effect.
CO	Present in flue gas as a result of incomplete combustion of waste. e.g., if spontaneously evaporating or rapid-burning substances are present, or when combustion gas mixing with the supplied oxygen is poor.
NO _x	Present in flue gas as both thermal and fuel NO _x . Fuel NO _x originates from the conversion of nitrogen contained in the waste while thermal NO _x results from the conversion of atmospheric nitrogen from the combustion air. In WTE the proportion of thermal NO _x is often much greater than fuel NO _x .
SO ₂	Present in flue gas where sulphur is present in the waste stream. Common sources of sulphur in the waste stream are: waste paper, drywall (or gypsum plaster) and sewage sludge.
N ₂ O	Principally arises from SNCR. Modern MSW incinerators have low combustion-originated N ₂ O but, depending on the reagent, emissions can result from SNCR, especially when urea is used as the reducing agent.
Methane (CH ₄)	Normally not generated at all as long as combustion is carried out under oxidative conditions. May arise from the waste bunker if waste is stored for a long time resulting in anaerobic digestion taking place.
Metals (Heavy metals and compounds other than Hg and Cd) Sb, As, Pb, Cr, Cu, Mn, Ni, V, Sn,	Predominantly found in flue gas as particulate matter usually as metal oxides and chlorides. A portion can also be found in bottom ash, fly ash and sorbent. The proportion of each metal found in the particulate entrained in the flue gas versus that found in the bottom ash, is usually reflective of the volatility of the metal.

⁵¹ Environment Agency, Pollution Inventory Reporting: Environmental Permitting (England and Wales) Regulations 2007, Regulation 60(2), December 2009

⁵² European Commission. 2006. Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 3: Potential Discharges from Thermal Treatment

Substances	Comments and Main Sources
Cd	Predominantly found in flue gas in gaseous form or bound to entrained PM. Common sources of cadmium in WTE facilities are electronic devices (including capacitors), batteries, some paints and cadmium-stabilized plastic. Other sources include hazardous wastes including effluent treatment sludges and drummed waste from metal plating works. It should be noted that BC is actively removing sources of cadmium from the waste stream with the electronic product stewardship program, and battery recycling see http://rcbc.bc.ca/education/retailer-take-back
Hg	Predominantly found in flue gas in gaseous form or bound to entrained PM. Originates from MSW containing batteries, thermometers, dental amalgam, fluorescent tubes, and mercury switches. High quantities of fish/seafood in the waste stream can also lead to mercury emissions. Also found in bottom ash, fly ash and sorbents. There are programs in place to remove mercury from the waste stream such as: Canada Wide Standards for Dental Amalgam Waste, and fluorescent light recycling product stewardship in BC.
VOCs (often presented as TOC)	Predominantly found in flue gas from incineration of organic waste. There is also some potential for fugitive releases from waste storage areas.
PAHs	Principally found in flue gas as products of incomplete combustion. Also found in bottom ash, fly ash and sorbents.
Dioxin like PCBs	Predominantly found in flue gas from most municipal waste streams and some industrial wastes. Low levels of PCBs are found in most municipal waste streams. Higher concentrations in some hazardous waste streams. Also found in bottom ash and APC Residue.
Dioxins and furans	Predominantly found in flue gas, as a result of re-combination reaction of carbon, oxygen and chlorine (de novo synthesis). May also be found in low levels in the incoming waste stream. Also found in boiler ash, bottom ash, fly ash and sorbents.
Ammonia	Predominantly found in flue gas where SNCR is used to control NO _x . May be present as a result of overdosing or poor control of reagents.
HCl	Predominantly found in flue gas from wastes containing chlorinated organic compounds or chlorides. In municipal waste approximately 50% of the chlorides come from PVC plastic (used for household sewerage pipes).
HF	Predominantly found in flue gas. Originates from fluorinated plastic or fluorinated textiles in MSW and a variety of fluorinated compounds found in household hazardous waste.

Like other combustion processes, WTE facilities can release small quantities of a broad spectrum of compounds into the atmosphere. Only a small fraction of these are considered to be air pollutants and are considered substances of concern. Typical substances of concern that are emitted from WTE facilities and often subject to regulatory limits include:

- Total Particulate Matter (including PM₁₀, PM_{2.5} and ultrafine (nanoparticles))
- Products of incomplete combustion: CO and Organic compounds (TOC, VOCs, organic matter)
- Acidic substances: SO_x, NO_x, HCl and HF
- Heavy metals: Hg, Cd, Tl, Pb, As, Ni, Co, Cr, Cu, V, Mn, Sb
- Organics: dioxins and furans.

Common or Criteria Air Contaminants (CACs) typically found in the atmosphere are PM, SO_x, NO_x, VOCs and CO. BC MOE Ambient Air Quality Objectives for these CACs are summarized in Section 8.1.2.3. Background information pertaining to each of the emitted WTE air pollutants of concern is provided below.

Particulate Matter

Particulate matter (PM) consists of solid and/or liquid particles that are suspended in the air column. PM is typically grouped into the following categories based on their aerodynamic diameter (in micrometers (µm)):

- Total Particulate Matter (TPM), consisting of all size fractions
- Coarse PM, less than 10 µm (PM₁₀)
- Fine PM, less than 2.5 µm (PM_{2.5})
- Ultrafine PM, less than 0.1 µm (PM_{0.1}).

In human physiology, coarse particles (those between 2.5 and 10 µm in diameter) are efficiently trapped and removed. They are either filtered out by the hair in the nose or by impacting on and sticking to moist surfaces in the upper respiratory tract. Coarse particles are mainly fine crustal elements. Coarse particles fall out of the atmosphere relatively quickly due to gravity and removal by precipitation.

Fine particles (those less than 2.5 µm in diameter) are able to penetrate deeper into the respiratory tract. Because of this property, fine particles are believed to be responsible for most adverse health effects associated with particulate matter exposure. Fine particles include very fine crustal elements and secondary particles that are essentially ultrafine particles that have formed into larger particles by a variety of physical and chemical processes (e.g., nucleation, condensation, coagulation). Fine particles persist in the atmosphere for long periods and travel long distances because they are relatively stable and their size makes them less susceptible to gravitational settling.

Canadian and American regulatory agencies have air quality objectives for PM₁₀ and more recently PM_{2.5} based upon concentrations in air (in micrograms per cubic metre (µg/m³)).

Ultrafine particles (PM_{0.1}) range in size from 0.1 to less than 0.01 µm in diameter (100 to <10 nanometre (nm)). Ultrafine particles are relatively short lived (minutes to hours) owing to the rapidity of the physical and chemical processes noted above.^{[53] [54]} Some authors use the term 'ultrafine particles' and 'nanoparticles' interchangeably to denote all particles in the nanometer size range. Some advocate the bifurcation of "ultrafine particles" as those between 100 to 10 nm in diameter, and "nanoparticles" as those less than 10 nm. Because of quantum effects, particles smaller than 10 nm in diameter behave differently than their bulk counterparts, and they are different morphologically

⁵³ AWMA, 2005a Nanoparticles and the Environment: Critical Review. Pratim Biswas and Chang-Yu Wu. JAWMA, v55, June 2005 pp 708 – 746

⁵⁴ AWMA, 2005b Nanoparticles and the Environment: Critical Review Discussion. Judith C. Chow, *et al.* JAWMA, v55, October 2005 pp 1411 – 1417

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 3: Potential Discharges from Thermal Treatment

and chemically compared to ultrafine particles^[55]. Research into the fate and behavior of particles of this size is ongoing. In this report, the designation PM_{0.1} will include ultrafine particles and nanoparticles unless otherwise designated.

The primary sources of PM_{0.1} include the condensation of hot vapours during high temperature combustion processes (i.e., diesel fumes, coal burning, welding, automobiles, wood fires), cooking of foods, biological processes, and secondary formations (i.e., from the nucleation of atmospheric species to form larger particles).^{[56] [57]}

Particles in the PM_{0.1} size range are ubiquitous in the atmosphere, and are at the heart of essential chemical and physical processes such as the sulphur and nitrogen cycle, and cloud formation. A growing body of literature is devoted to the measurement and study of the effects of PM_{0.1}.^[58] Since simple filtration is ineffective at capturing such small particles, measurements focus on particle sizing and particle number (count) by inertial impaction, electrical, and light scattering means.

In addition to size and concentration, the toxicity of nanoparticles is correlated with chemical composition. Smaller particles have proportionally greater surface area per mass and can interact more readily with cell surfaces. With the increase in surface area, the physical parameter of the surface Gibbs free energy increases causing the particles to be more chemically reactive with the surrounding tissue.^[59] As a consequence, health effects resulting from nanoparticles are not correlated with the total mass of particles entering the organism. Insoluble and non-soluble PM_{0.1} are of greatest concern because they eventually accumulate and can lead to toxic effects in specific organs (i.e., heart, lungs, reproductive system).^[60]

In addition to chemical composition, other factors such as surface dose, surface coverage, surface charge, shape, porosity, and the age of the particle can contribute to the toxicity of particles in the ultrafine range. However, not enough data is currently available to assess the significance of each of these factors on the toxicity of PM_{0.1}.

The current understanding of adverse health effects of exposure to PM_{0.1} indicates that the effects are as diverse as the types of particles themselves, making it very difficult to identify major trends. A detailed summary of the current state of knowledge of the impact of different types of PM_{0.1} on human health was completed by the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) in 2008.

Carbon Monoxide

Carbon monoxide is a colourless, odourless gas. As a product of incomplete combustion, emissions sources include fossil fuel and wood combustion. Motor vehicles, industrial processes, and natural sources (fires) are some common sources.

⁵⁵ AWMA, 2005a Nanoparticles and Environment: Critical Review. Pratim Biswas and Chang-Yu Wu. JAWMA, v55, June 2005 pp 708 – 746

⁵⁶ Health Canada. National Ambient Air Quality Objectives for Particulate Matter – Executive Summary. Part 1: Science Assessment Document

⁵⁷ The Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST). Health Effects of Nanoparticles. November, 2008

⁵⁸ AWMA, 2005a Nanoparticles and Environment: Critical Review. Pratim Biswas and Chang-Yu Wu. JAWMA, v55, June 2005 pp 708 – 746

⁵⁹ The Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST). Health Effects of Nanoparticles. November, 2008

⁶⁰ The Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST). Health Effects of Nanoparticles. November, 2008

Volatile Organic Compounds (VOCs)

Volatile Organic Compounds are organic substances of concern (carbon chains or rings that also contain hydrogen) that have high enough vapour pressures under normal conditions to significantly vapourize and enter the Earth's atmosphere (i.e., with a vapour pressure greater than 2 mm of mercury (0.27 kPa) at 250°C or a boiling range of between 60 and 250°C) excluding methane. Individual jurisdictions have varying definitions for VOCs that may be tailored to the specific regulatory context in which the definition is applied. These gaseous organic substances are products of incomplete combustion. For WTE facilities, generally Total Organic Carbon (TOC) or Total Non-Methane Organic Carbon (TNMOC) which is largely comprised of VOCs, is measured continuously in flue gas as being representative of the mass of VOC emissions. This is necessary as there are a myriad of species of VOCs that may be present in extremely small concentrations within the flue gas and monitoring of individual species is not possible.

Sulphur Dioxide

Sulphur dioxide is a colourless gas with a distinctive pungent sulphur odour. It is produced in combustion processes by the oxidation of sulphur compounds, such as H₂S, in fuel. At high enough concentrations, SO₂ can have negative effects on plants and on animal health, particularly with respect to their respiratory systems. Sulphur dioxide can also be further oxidized and may combine with water to form the sulphuric acid component of acid rain.

Anthropogenic emissions comprise approximately 95% of global atmospheric SO₂. The largest anthropogenic contributor to atmospheric SO₂ is the industrial and utility use of heavy oils and coal. The oxidation of reduced sulphur compounds emitted by ocean surfaces accounts for nearly all of the biogenic emissions. Volcanic activity accounts for much of the remainder.^[61]

Oxides of Nitrogen

Nitrogen oxides are produced in most combustion processes, and almost entirely made up of nitric oxide (NO) and nitrogen dioxide (NO₂). Together, they are often referred to as NO_x. Nitrogen dioxide is an orange to reddish gas that is corrosive and irritating. Most NO₂ in the atmosphere is formed by the oxidation of NO, which is emitted directly by combustion processes, particularly those at high temperature and pressure, such as internal combustion engines.

Nitric oxide is a colourless gas with no apparent direct effects on animal health or vegetation at typical ambient levels. The concentration of NO₂ is the regulated form of NO_x. External combustion processes, such as gas-fired equipment and motor vehicles, are primary sources of anthropogenic NO_x emissions. The levels of NO and NO₂, and the ratio of the two gases, together with the presence of certain volatile organic compounds (VOCs) from motor vehicle emissions, solvent use and natural sources, and sunlight are the most important contributors to the formation of ground-level ozone.

Anthropogenic emissions comprise approximately 93% of global atmospheric emissions of NO_x (NO and NO₂). The largest anthropogenic contributor to atmospheric NO_x is the combustion of fuels

⁶¹ Wayne, R. Chemistry of Atmospheres. Oxford Science Publications, 1991.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 3: Potential Discharges from Thermal Treatment

such as natural gas, oil, and coal. Forest fires, lightning, and anaerobic processes in soil account for nearly all biogenic emissions.^[62]

Acid Gases

Acid gases are those gaseous contaminants which contribute towards the formation of acidic substances in the atmosphere. In combustion, acid gases of concern include sulphur dioxide (SO₂), oxides of nitrogen (NO_x), hydrogen chloride (HCl) and hydrogen fluoride (HF).

Heavy Metals

Heavy metals are usually carried on particulate matter and occur naturally or can be emitted through anthropogenic sources (i.e., combustion). The concern for human and ecological health varies with each metal as well as its mobility through various environmental pathways. Some metals (such as mercury) have toxic effects if inhaled, ingested or absorbed through skin. Typical metals emitted as a result of MSW combustion include cadmium, thallium, chromium, arsenic, mercury and lead. Semi-volatile metals include lead or cadmium whereas mercury and thallium are highly volatile and vapourize readily.

Dioxins and Furans

Dioxins and Furans are organic compounds with a chemical structure that contains two benzene rings and up to eight chlorine atoms. They can be created as an undesired by-product of chemical processes such as the manufacture of pesticides, or chlorine bleaching of pulp. Dioxins and Furans can also be produced under certain conditions within combustion processes in which chlorine is present in the fuel burned, or where poor combustion operating conditions can result in de novo synthesis (as discussed below). Normally, a well functioning incinerator facility will destroy dioxins and furans within the combustion zone. The reference dioxin isomer is 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD). Other isomers are usually expressed in terms of equivalents of TCDD. TCDD is almost insoluble in water, slightly soluble in fats and more soluble in hydrocarbons.

Dioxins and furans may form (referred to as de novo synthesis) in catalytic reactions of carbon or carbon compounds with inorganic chlorine compounds over metal oxides (e.g., copper oxide) during the waste incineration process. These reactions generally take place in the temperature range between 250 – 400°C which occurs as the flue gas cools after leaving the combustion zone of the incinerator. Modern incinerators are designed to ensure that the length of time flue gas spends in that temperature range is minimized so as to reduce the possibility of de novo synthesis of dioxins/furans and to control and destroy dioxin and furan in the emission before discharge.

3.1.2 Point Source Emissions

Point source emissions are those emissions resulting from a single point such as the emissions exhausted via a stack or vent, i.e., a single point source into the atmosphere. Point source emissions are usually the most significant emission source (in terms of annual mass releases) for combustion activities at WTE facilities. APC equipment (e.g., scrubbing units, fabric filters (bag house)) as

⁶² Wayne, R. Chemistry of Atmospheres. Oxford Science Publications, 1991

described further in this report, are incorporated into the exhaust system prior to discharge to atmosphere control the release of pollutants into the atmosphere.^[63] Point source emissions at a WTE facility are those that contain the treated exhaust from the process and typically it is this exhaust stream that is monitored for compliance with regulatory limits.

3.1.3 Fugitive Emissions

Fugitive emissions are those that are not released from a point source such as a stack, but rather from an area-based source. Typically fugitive emissions are uncontrolled, or are controlled on an as-needed basis, such as through the use of dust suppression techniques in dry conditions. Fugitive emissions from WTE facilities, including dust, odour and VOCs, are largely minimized by maintaining the WTE facility under negative pressure, using indoor facility air for combustion. Some examples of areas with potential for fugitive emissions and potential mitigative measures are:

- The loading and unloading of transport containers. To mitigate fugitive emissions from receiving areas these areas are usually fully enclosed, and the air from these areas is drawn into the combustion process, keeping the waste receiving area under negative pressure.
- Storage areas (e.g., bays, stockpiles, etc) for waste and residual materials. As noted above, mitigation includes enclosing these areas and using the air from these locations as sources for combustion air.
- Transferring material between vessels (e.g., movement of materials to and from silos, transfer of volatile liquids such as select liquid fuels). Filters are commonly added on silos for lime and other dusty materials.
- Conveyor systems, which are usually enclosed.
- Pipe work and ductwork systems (e.g., pumps, valves, flanges), which are maintained to prevent accidental losses.
- Abatement equipment by-pass, which must be designed to allow for retention of any accidental emissions.
- Accidental loss of containment from failed plant and equipment.
- Oil and ammonia storage tanks, which require appropriate preventative maintenance and other practices to ensure containment.^[64]

Generally the regulation of potential fugitive emissions from a WTE facility is addressed through the approval of the site specific design and operations plans for the facility and the issuance of the required permits for the facility operation, including specific terms and conditions that reflect the requirements for design and operation.

3.1.4 Factors Affecting Airshed Impacts

The addition of a new emission source within an airshed has the potential to impact ambient air quality. The potential impacts are a function of a number of factors:

⁶³ Environmental Agency. 2009. Pollution Inventory Reporting

⁶⁴ Durham/York Residual Waste Study Environmental Assessment, November 27, 2009, Stantec Consulting Limited

- **Discharge Characteristics.** The increase in mass loading to an airshed of contaminants of concern from a new facility has the potential to degrade ambient air quality. The greater the discharge rate, the greater the potential risk. Air pollution control systems are specifically designed to reduce the discharge of these constituents such that the impact is considered to be acceptable. The temperature and velocity of the discharge also can affect the effect on airshed quality. Generally, hotter and higher velocity discharges will disperse further from the point of discharge, effectively reducing ambient concentrations of the constituents of concern. The chemical reactivity of the constituents in the discharge will also determine the fate and behaviour in the ambient air. Stable compounds and small particulate may remain suspended in the airshed for a long time, whereas unstable compounds or large particulate will experience a shorter residence time in the ambient air.
- **Airshed Characteristics.** The dispersion and physical/chemical reactions of constituents are governed by the characteristics of the airshed. Topography, latitude, temperature, prevailing wind direction and pre-existing emissions all affect the dispersion of a discharge, and therefore affect the fate and behaviour of the constituents in the atmosphere. Some airsheds are affected by a combination of factors. For example, the lower Fraser Valley is a complex airshed, with confining mountains forming a basin around the river valley, prevailing winds that transport the air mass up and down the valley, seasonal 'sea breeze' effects that result in a daily reversal of wind direction, and a photochemical sensitivity to NO_x and volatile hydrocarbon emissions that react with sunlight to form elevated concentrations of low level ozone.

Examination of the permitted and actual emissions from WTE facilities (as shown in Table 5-2) that have been recently designed and are operating in a manner consistent with BACT indicates that the concentrations of the constituents of concern (Criteria Air Contaminants, Hazardous Air Pollutants, among other definitions) are quite low and often at least an order of magnitude less than their regulated limits. In comparison to other existing combustion-based industries, WTE facilities typically have lower discharge concentrations of the constituents of concern. While a new WTE facility will add, on a mass basis, additional constituents into the airshed, the increment will in almost all cases be insignificant in terms of overall ambient air quality and increased risk to human health and the environment. The proponents of a new facility have an obligation to demonstrate that this is the case through detailed meteorological and dispersion modeling studies and by quantitative human health and ecological risk assessment (HHERA) studies. One of the more recent examples of such site specific air modeling and HHERA studies undertaken in Canada for a WTE facility, are the recently completed studies for the Durham York Residual Waste EA Study.^[65]

3.2 Liquid Effluents

In addition to emissions to air, some WTE facilities also generate an effluent discharge. Whether or not an effluent discharge is produced depends on the type of APC system used as well as other design parameters.

⁶⁵ Stantec Consulting Limited. 2009. Durham/York Residual Waste Study Environmental Assessment.

Effluent management is more often required for WTE facilities that include wet scrubbers as a component in the APC train, (i.e., facilities with a wet APC train). Facilities that use other alternatives to control acid gases, as discussed in Section 4, generally are designed as zero effluent discharge facilities, and if they are likely to generate any effluent it would typically include storm water and/or sanitary wastewater which can easily be managed by conventional storm water and wastewater control systems.

Water is used at WTE facilities for various processes and effluent may result from any of the following sources.^{[66] [67]}

- APC process wastewater – normally from wet flue gas treatment (dry and semi-dry systems do not typically give rise to any effluent) although not all wet systems produce effluent that needs to be discharged from the facility (discussed further below).
- Wastewater from collection, treatment and (open-air) storage of bottom ash – not usually discharged but used as water supply for wet de-slaggers.
- Other process wastewater streams – e.g., wastewater from the water/steam cycle resulting from the preparation of boiler feed water and from boiler drainage. In many cases this water can be reused in the incineration and APC treatment process as make-up water and does not result in actual discharge from the facility.
- Sanitary wastewater (e.g., toilets and kitchen).
- Stormwater which originates from precipitation falling on surfaces such as roofs, service roads and parking lots and is usually discharged directly to storm sewers, though may receive passive or active treatment if storm water management is in place. Storm water may also be generated at waste unloading areas if these areas are uncovered. Such storm water would usually be segregated from other sources and treated prior to discharge.
- Used cooling water (e.g., cooling water from condenser cooling).

WTE facilities that utilize dry or semi-dry APC systems are often designed with zero wastewater discharge. This is accomplished via the reuse of wastewater produced by a facility. For example, facilities that utilize semi-dry APC systems can reuse boiler blowdown and reject water from the boiler as scrubber slaking and dilution water. As mentioned previously in this report, semi-dry and dry APC systems are the most common type used in North America.

WTE facilities that utilize wet APC systems can also be designed as zero wastewater discharge facilities but require a wastewater treatment system that allows the effluent resulting from the wet scrubbers to be re-used within the facility. The wastewater resulting from wet flue gas treatment

⁶⁶ Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT for the Incineration of Waste.

⁶⁷ European Commission. 2006. Integrated Pollution Prevention and Control: Reference Document on the Best Available Techniques for Waste Incineration.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 3: Potential Discharges from Thermal Treatment

contains a wide variety of contaminants including heavy metals, inorganic salts (sulphates) and organic compounds (including dioxins/furans).^[68]

There are three main alternatives for the treatment or reuse of wastewater from wet flue gas treatment systems:

- **Physical/chemical treatment** – based on pH-correction and sedimentation. With this system a treated wastewater stream containing some dissolved salts must be discharged if not evaporated using one of the following two evaporation processes listed below.
- **In-line evaporation of process wastewater** – by means of a semi-dry system (e.g., for systems that use wet and semi-dry APC systems). In this case the dissolved salts are incorporated into the residue of the APC system. There is no discharge wastewater other than that evaporated with the flue gases.
- **Separate evaporation of wastewater** – the evaporated water is condensed, but can be discharged (or reused) without special measures.

As noted above the physical/chemical treatment and separate evaporation methods may result in a potential effluent discharge from the facility.

Table 3-2 provides an example of the composition of untreated effluent from MSW incinerators that utilize wet flue gas treatment systems. Typical contaminant concentrations following treatment are also indicated.

Table 3-2: Composition of Effluent from MSW Incinerators that Utilize Wet Flue Gas Treatment Systems

Parameter	Units	Average Before Treatment ^[69]	Typical Effluent Discharge Values from Dutch MSW Incinerators (2002) ^[70]	Range of Effluent Discharge Values from Austrian MSW Incinerators (2001) ^[71]
pH	–	–	–	6.8 – 8.5
TOC	mg/l	73,000	–	4.3 – 25
Sulphate	g/l	4,547	–	<1.2
Chloride	g/l	115,000	–	7 – <20
Fluoride	mg/l	25,000	–	<0.006 – <10
As	mg/l	–	0.01	<0.003 – <0.05
Hg	mg/l	6,200	0.005	<0.001 – <0.01
Pb	mg/l	250	0.1	<0.01 – <0.1
Cu	mg/l	100	0.02	<0.05 – <0.3
Zn	mg/l	690	0.2	<0.05 – <0.5

⁶⁸ European Commission. 2006. Integrated Pollution Prevention and Control: Reference Document on the Best Available Techniques for Waste Incineration.

⁶⁹ Draft of a German Report with Basic Information for a BREF-Documents “Waste Incineration”. 2001. German Federal Environmental Agency

⁷⁰ Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT for the Incineration of Waste

⁷¹ Federal Environment Agency – Austria. 2002. State of the Art for Waste Incineration Plants

Parameter	Units	Average Before Treatment ^[69]	Typical Effluent Discharge Values from Dutch MSW Incinerators (2002) ^[70]	Range of Effluent Discharge Values from Austrian MSW Incinerators (2001) ^[71]
Cr	mg/l	170	0.03	<0.05 – <0.1
Ni	mg/l	240	0.03	<0.05 – <0.5
Cd	mg/l	8	0.05	<0.001 – <0.05
Sn	mg/l	–	0.05	0.06
Mo	mg/l	–	1	–
Tl	mg/l	–	–	<0.01 – 0.02
PCDD/PCDF	ng/l	–	1,000	–

NOTES:

(–) means the value is not provided

Refer to Table 3-3 in Section 3.2.4 for an example of BAT discharge limit values for effluent resulting from MSW incinerators.

The following subsections describe each of the three primary wastewater treatment methods in more detail.

3.2.1 Physical/Chemical Treatment

The following figure (Figure 3-1) illustrates a typical configuration of a physical/chemical treatment unit for scrubber wastewater:

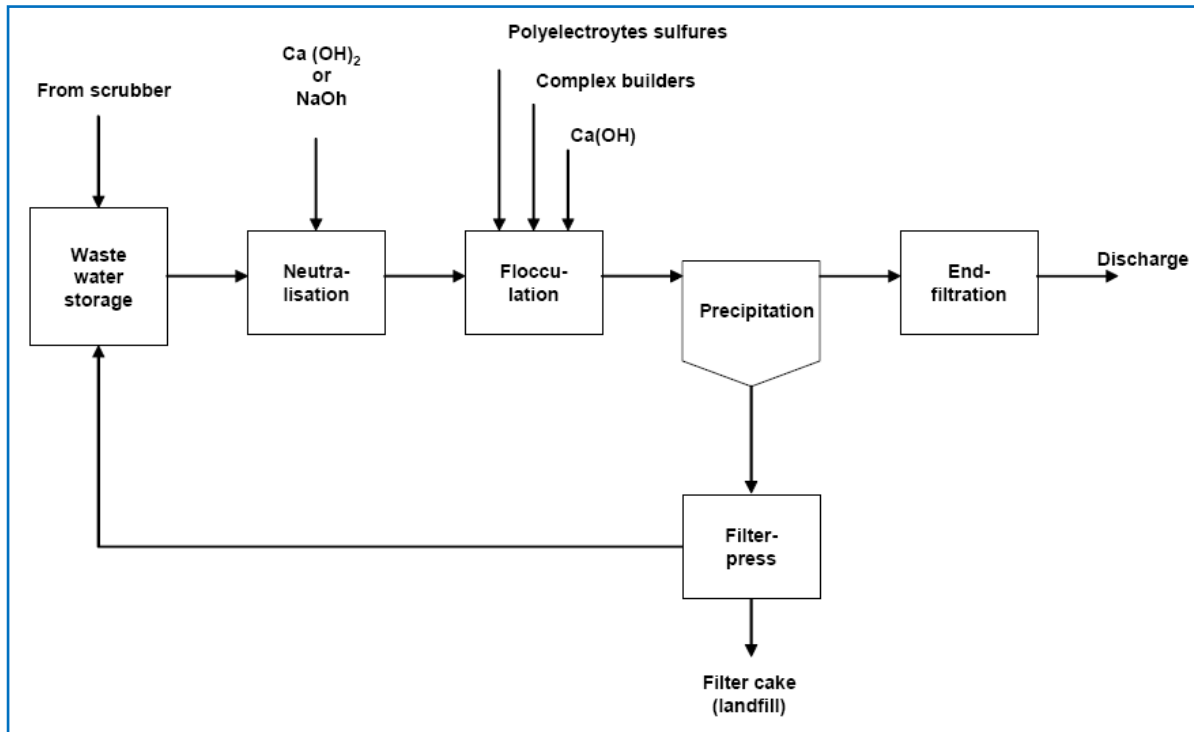
Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 3: Potential Discharges from Thermal Treatment

Figure 3-1: Schematic Illustrating Physical/Chemical Treatment of Wastewater from a Wet APC System^[72]



Source: Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT for the Incineration of Waste

The process consists of the following steps:

- pH neutralization – normally lime is used resulting in the precipitation of sulphites and sulphates (gypsum)
- Flocculation and precipitation of heavy metals and fluorides – takes place under the influence of flocculation agents (poly-electrolytes) and FeCl_3 ; additional complex builders can be added for the removal of mercury
- Gravitation (precipitation) of the formed sludge – takes place in settling tanks or in lamellar separators
- Dewatering of sludge – normally achieved through dewatering filter presses
- End-filtration of the effluent (polishing) – via sand filters and/or activated carbon filters, removing suspended solids and organics such as dioxins/furans (if activated carbon is used).

⁷² Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT for the Incineration of Waste.

In addition to the process steps listed above, facilities may also apply:

- Sulphides for heavy metal removal
- Membrane technologies for removal of salts
- Ammonia stripping (if SNCR is used to control NO_x)
- Separate treatment of wastewater from the first and last steps of the scrubber system (allows for the production of high quality gypsum)
- Anaerobic biological treatment to convert sulphates into elemental sulphur.

3.2.2 In-line Evaporation of Wastewater

With this treatment option, the wastewater is reused in the process line in a spray-dryer. The waste water containing soluble salts is first neutralized and then injected into the flue gas stream. The water evaporates and the remaining salts and other solid pollutants are removed in the dust removal step of the APC train (e.g., bag filter). The neutralization step can be combined with flocculation and the settling of pollutants, resulting in a separate residue (filter cake). In some systems, lime is injected into the spray absorber for gas pre-neutralization.

This method is only employed at facilities that utilize spray-dryers and wet scrubbers. A spray dryer functions in a similar way to a spray adsorber (used in semi-dry APC systems). The main difference between the two is that the spray dryer uses wastewater from the wet scrubber (instead of lime) after the wastewater has been neutralized.

Figure 3-2 presents a schematic overview of in-line evaporation of wastewater.

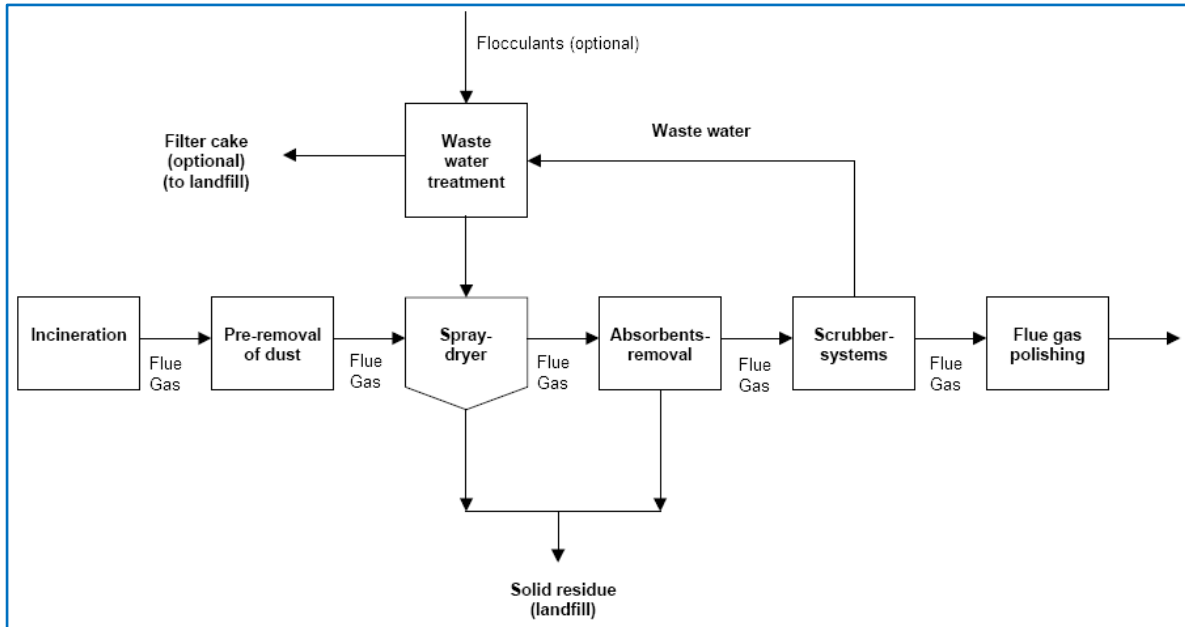
Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 3: Potential Discharges from Thermal Treatment

Figure 3-2: Schematic Illustrating In-line Evaporation of Wastewater^[73]



Source: Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT for the Incineration of Waste

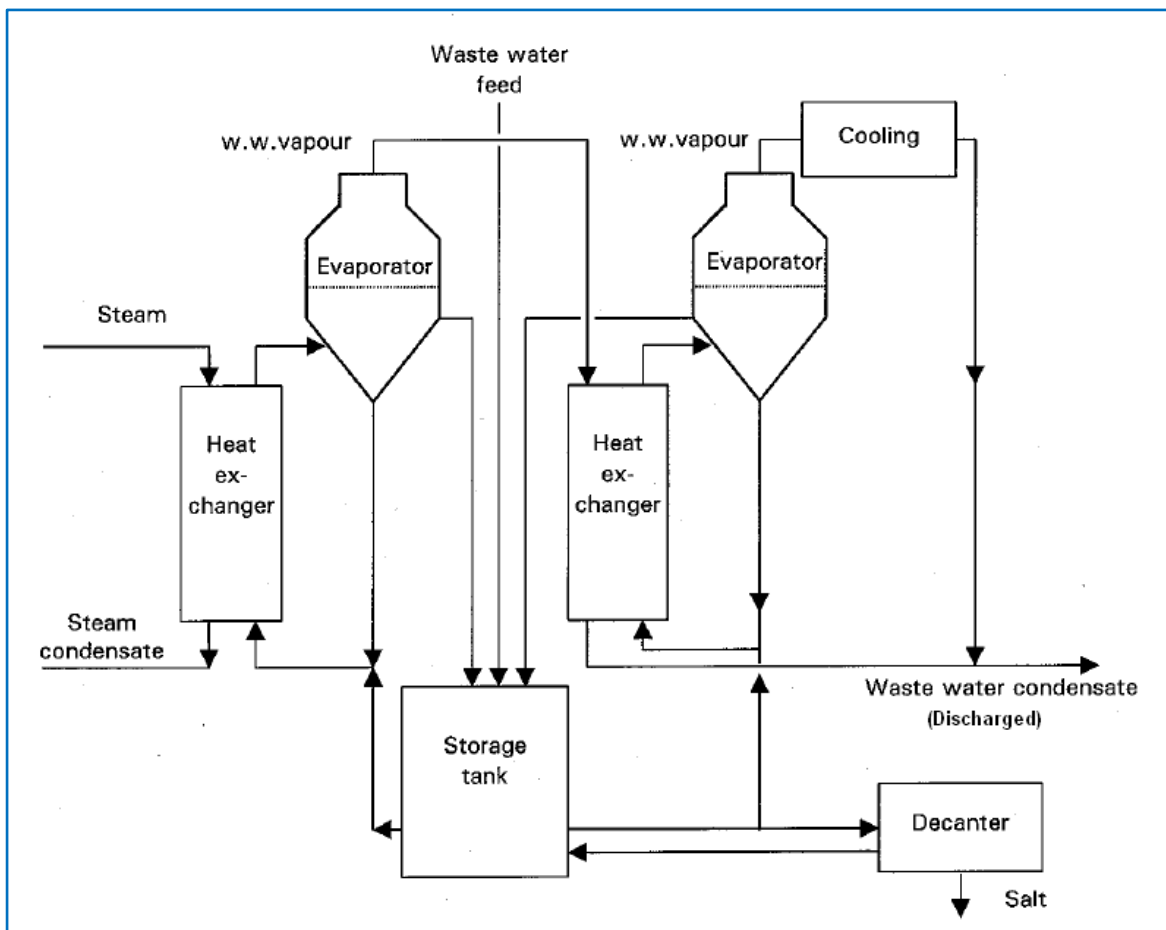
3.2.3 Separate Evaporation of Wastewater

In this process, wastewater is evaporated using a steam heated evaporation system. Wastewater is fed into a storage tank where it is heated (using heat supplied via a heat-exchanger). The heat acts to partially evaporate the liquid out of the storage tank. The un-evaporated liquid flows back to the storage tank while the vapours produced by evaporation eventually cool down resulting in a clean condensate which can be discharged directly from the facility. As evaporation continues the salt concentrations in the liquid rise, resulting in crystallization of the salts which can be separated in a decanter and collected in a container and disposed of in a landfill.

Figure 3-3 displays a two-stage process with two evaporators installed, where the input of heat into the second evaporator is the vapour from the first evaporator (results in less energy demand).

⁷³ Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT for the Incineration of Waste.

Figure 3-3: Schematic Illustrating Separate Evaporation of Wastewater^[74]



Source: Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT for the Incineration of Waste

3.2.4 BAT for Effluent Management

As discussed in Section 3.2, effluent management is more often required for WTE facilities that include wet scrubbers as a component in the APC train, (i.e., facilities with a wet APC train).

The following effluent treatment and operational parameters for wet APC systems are considered BAT.^{[75] [76] [77]}

⁷⁴ Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT for the Incineration of Waste

⁷⁵ Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on Bat

⁷⁶ Federal Environment Agency – Austria. 2002. State of the Art for Waste Incineration Plants

⁷⁷ European Commission. 2006. Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 3: Potential Discharges from Thermal Treatment

- The use of onsite physical/chemical treatment of effluent prior to discharge to achieve at the point of discharge from the effluent treatment plant (ETP) effluent concentrations within the range identified in Table 3-3.^[78]
- The separate treatment of the acid and alkaline wastewater streams arising from scrubber stages when there are particular drivers for additional effluent discharge reduction, and/or where HCl and/or gypsum recovery is to be carried out.
- The re-circulation of wet scrubber effluent within the scrubber system so as to reduce scrubber water consumption and in general the re-circulation and re-use of wastewater arising from the site (i.e., using boiler drain water for reuse in the wet scrubber).
- The provision of storage/buffering capacity for effluents to provide for a more stable treatment process.
- The use of sulphides or other mercury binders to reduce mercury in the treated effluent.
- The assessment of dioxin and furan build up in the scrubber and adoption of suitable measures to prevent scrubber breakthrough of these contaminants.
- When SNCR is used the ammonia levels in the effluent may be reduced using ammonia stripping and the recovered ammonia re-circulated for use in the SNCR.

Table 3-3: BAT Associated Operational Emissions Levels for Discharges of Wastewater from Effluent Treatment Plants Receiving APC Scrubber Effluent^[79]

Parameter	BAT Range in mg/L (unless stated)	Sampling and Data Information
Total Suspended Solids	10 – 30 (95%) 10 – 45 (100%)	Based on 'spot daily' or 24 hour flow proportional sample
Chemical Oxygen Demand	50 – 250	Based on 'spot daily' or 24 hour flow proportional sample
pH	6.5 – 11	Continuous measurement
Hg and its compounds	0.001 – 0.03	Based on monthly measurements of a flow proportional representative sample of the discharge over a period of 24 hours with one measurement per year exceeding the values given, or no more than 5% where more than 20 samples are assessed per year.
Cd and its compounds	0.01 – 0.05	
Tl and its compounds	0.01 – 0.05	
As and its compounds	0.01 – 0.15	
Pb and its compounds	0.01 – 0.1	Total Cr levels below 0.2 mg/L provide for control of Chromium VI.
Cr and its compounds	0.01 – 0.5	Sb, Mn, V and Sn are not included in Directive 2000/76. Average of six monthly measurements of a flow proportional representative sample of the discharge over a period of 24 hours.
Cu and its compounds	0.01 – 0.5	
Ni and its compounds	0.01 – 0.5	
Zn and its compounds	0.01 – 1.0	

⁷⁸ European Commission. 2006. Integrated Pollution Prevention and Control: Reference Document on the Best Available Techniques for Waste Incineration.

⁷⁹ European Commission. 2006. Integrated Pollution Prevention and Control: Reference Document on the Best Available Techniques for Waste Incineration.

Parameter	BAT Range in mg/L (unless stated)	Sampling and Data Information
Sb and its compounds	0.05 – 0.85	
Co and its compounds	0.005 – 0.05	
Mn and its compounds	0.02 – 0.2	
V and its compounds	0.03 – 0.5	
Sn and its compounds	0.02 – 0.5	
PCDD/F (TEQ)	0.01 – 0.1 ng TEQ/L	

NOTES:

1. Values are expressed in mass concentrations for unfiltered samples
2. Values relate to the discharge of treated scrubber effluents without dilution
3. BAT ranges are not the same as ELVs
4. pH is an important parameter for wastewater treatment process control
5. Confidence levels decrease as measured concentrations decrease towards lower detection levels

SPLIT VIEWS:

1. BAT 48: One Member State and the Environmental NGO expressed split views regarding the BAT ranges. These split views were based upon their knowledge of the performance of a number of existing installations, and their interpretation of data provided by the thematic working group (TWG) and also of that included in the BREF document. The final outcome of the TWG meeting was the ranges shown in the table above but with the following split views recorded: Hg 0.001 – 0.01 mg/l; Cd 0.001 – 0.05 mg/l; As 0.003 – 0.05 mg/l; Sb 0.005 – 0.1 mg/l; V 0.01 – 0.1 mg/l; PCDD/F <0.01 – 0.1 ng TEQ/l.
2. BAT 48: Based on the same rationale, the Environmental NGO also registered the following split views: Cd 0.001 – 0.02 mg/l; TI 0.001 – 0.03 mg/l; Cr 0.003 – 0.02 mg/l; Cu 0.003 – 0.3 mg/l; Ni 0.003 – 0.2 mg/l; Zn 0.01 – 0.05 mg/l; PCDD/F <0.01 ng TEQ/l.

As discussed previously in Section 3.2, not all WTE facilities that utilize Wet APC systems actually produce effluent discharge. Refer to Section 3.2.2 and 3.2.3 for a full description of these techniques.

3.3 Solid Wastes

Waste incineration leads to weight and volume reduction of wastes. The solid wastes generated by WTE facilities will vary based on the design of the plant, and can consist of: reject wastes (removed prior to combustion), bottom ash, metallic scrap, APC residues, slag (depending on the facility design), filter cake from wastewater treatment, gypsum and loaded activated carbon. These material streams are discussed briefly below.

3.3.1 Reject Waste

The MSW stream commonly includes various materials that should not enter the combustion chamber either as they will not efficiently combust due to their size and composition (e.g., metal appliances) or as they could cause damage within the combustion unit (e.g., propane tank). Depending on the design of the WTE facility, there will be a specified range of materials that will be identified as unacceptable for combustion. Generally, screening and removal of these materials will take place on the floor of the reception building as each load of material is emptied onto the tipping floor/bunker. In addition, operators who manage the loading of the combustion chambers also remove certain materials when they are observed in the loading process. Generally, approximately

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 3: Potential Discharges from Thermal Treatment

2% of the waste received at a WTE will be rejected and removed for alternate disposal. In addition, depending on the length of the scheduled or unscheduled down-time associated with plant maintenance, it is possible MSW would have to be redirected to alternate disposal.

3.3.2 Bottom Ash

Bottom ash is the mineral material left after the combustion of the waste. Bottom ash is a heterogeneous mixture of slag, metals, ceramics, glass, unburned organic matter and other non-combustible inorganic materials, and consists mainly of silicates, oxides and carbonates. Typically, bottom ash makes up approximately 20 – 25% by weight or 5 to 10% by volume of the original waste.^[80] At most incineration facilities, bottom ash is mechanically collected, cooled and magnetically or electrically screened to recover recyclable metals. The remaining residue is either disposed of at a landfill, or alternatively, it may be used as a construction aggregate substitute.^[81] Further information is presented in Section 9.1.1 and 9.3. In some cases (e.g., gasification) the mineral material left after combustion of the waste is generated as a slag, but is generally managed in a similar fashion as bottom ash.

3.3.3 Recycling of Metals

Most WTE facilities include equipment to remove ferrous metals from the bottom ash. Recovery of non-ferrous metals (primarily aluminum) has also become more common. Depending on the composition of the incoming MSW stream, recovered metals can represent up to 10% of the input tonnage to the WTE facility. Generally, WTE facilities can recover approximately 80% of ferrous and 60% of non-ferrous metals present in the bottom ash. Separated metallic scrap is either delivered to a scrap dealer or returned to the steel industry.

3.3.4 Primary APC Residues

APC residues are the residues resulting from the APC system and other parts of incinerators where flue gas passes (i.e., superheater, economizer). APC residues are usually a mixture of lime, fly ash and carbon and are normally removed from the emission gases in a fabric filter baghouse.

APC residues contain high levels of soluble salts, particularly chlorides, heavy metals such as cadmium, lead, copper and zinc, and trace levels of dioxins and furans. The high levels of soluble, and therefore leachable, chlorides primarily originate from polyvinyl chloride (PVC) found in MSW. Typically, APC residues make up approximately 2 – 4% by weight of the original waste.^[82] Generally APC residues are managed separately from bottom ash as they are often classified as a hazardous waste. Common practice for APC residue management is to stabilize or otherwise treat these

⁸⁰ AECOM Canada Ltd. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling. June, 2009.

⁸¹ AECOM Canada Ltd. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling. June, 2009.

⁸² Algonquin Power Energy from Waste Facility Fact Sheet, <http://www.peelregion.ca/pw/waste/facilities/algonquin-power.htm#ash>

residues and/or to dispose of them at a hazardous waste facility. Methods of managing these residues are discussed in Sections 9.1.2 and 9.3.

3.3.5 Other APC Residues

Other residues generated by APC systems generally consist of used reagent materials (e.g., activated carbon) or residues recovered through effluent treatment. The generation of these other APC residues is dependent on the APC design. In general, the filter cake from wastewater treatment is heavily charged with Hg, Zn and Cd. In most cases it must be managed as a hazardous waste and treated or disposed of at secure hazardous waste facilities. For WTE facilities that use activated carbon in their APC train, it has become more common to combust the loaded activated carbon together with waste.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 3: Potential Discharges from Thermal Treatment

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4 AIR EMISSIONS CONTROLS

When using any WTE technology to treat MSW, some emissions to air are produced. In conventional combustion, the emissions to air are the result of the actual combustion of MSW. In gasification or pyrolysis, the emissions to air are associated with the combustion of the syngas or pyrolysis products to produce usable energy.

Over the years, vast technological improvements have been made which have assisted in greatly reducing the quantity and toxicity of emissions being released into the atmosphere. Generally speaking, these emissions controls can be grouped into two main categories:

- Operational controls, which act to increase the efficiency of the WTE process leading to lesser production of harmful emissions
- Air Pollution Control (APC) systems, which are usually placed on the back end of a WTE facility and act to capture/treat emissions before they are released.

The following two subsections discuss these operational controls and air pollution control systems. Both of these controls are primarily discussed as they relate to mass burn incineration (conventional combustion) facilities as this is the most common form of WTE technology being used worldwide to treat MSW. Some information regarding operational and APC systems for gasification is also provided, however, much less information is available in comparison to that available for mass burn incinerators as there are very few gasification facilities in operation worldwide that treat MSW in comparison to hundreds of mass burn incinerators. As mentioned previously in this report, gasification is less commercially proven than mass burn incineration in the treatment of MSW.

Little information is available regarding the emissions controls applicable for other WTE technologies.

4.1 Operational Controls

There are a number of operational controls^[83] used in modern WTE facilities that act to increase system performance and efficiency and by doing so, assist in reducing the formation of unwanted byproducts and pollutants. Operational controls act to reduce emissions (to air and water) and also assist in improving the quality of ash produced by a WTE facility. These operational controls are in addition to conventional “back end” air pollution controls that will be discussed further in Section 4.2.

Many of these operational controls have been developed over time as the understanding of WTE processes has increased. This understanding has allowed engineers to fine-tune the waste treatment process to prevent or reduce the creation of unwanted byproducts during waste treatment rather than having to remove these byproducts at the back end of a facility using air pollution control equipment. As mentioned earlier, these operational controls have also helped to increase the performance and efficiency of waste treatment technologies. Better operational controls allow for

⁸³ Much of this material adapted from A.J. Chandler and Associates Ltd. 2006. Review of Dioxins and Furans from Incineration in Support of a Canada-wide Standard Review

more environmentally and economically friendly operation of WTE facilities, and are one of the reasons why such WTE approaches are more broadly accepted in jurisdictions such as the EU.

The operational controls currently being used in modern mass burn incinerators (conventional combustion) and gasification facilities are discussed below.

4.1.1 Operational Controls for Mass Burn Incineration (Conventional Combustion)

In mass burn incinerators, operational controls have been developed to reduce the formation and release of unwanted byproducts (such as NO_x, dioxins/furans, and CO) during the incineration of MSW. Modern mass burn incinerators are designed with highly complex operational controls that ensure the safe and efficient combustion of waste with the accompanying capture of energy.

The operational/combustion controls used in mass burn incinerators compensate for the compositional variability of MSW and act to control the rate of combustion reactions.

The composition of MSW is highly variable and depends on a number of uncontrollable factors such as the general behavior of residents, use of available waste diversion programs and the demographics of the community the WTE facility serves.

The variable composition of MSW affects operational efficiency because each component of the waste stream has its own particular energy content which must be matched with a particular amount of oxygen to ensure proper and efficient combustion of the waste stream. For example, if a large amount of paper is being placed in the refuse stream, this will increase the overall energy content of the material and affect its behavior as a fuel source. In order to ensure that proper combustion conditions are met, the MSW stream must be made as homogenous as possible before and during incineration.

One way to increase the homogeneity of MSW is to ensure that the waste material is well mixed prior to being combusted. This can be accomplished by mixing waste with the grapple crane prior to placing the waste material into the hopper. Even after proper mixing, however, MSW heat values are still quite variable.

This variability is accounted for within the furnace by operational controls. Mass burn incinerators monitor the heat being released from the waste at all times and are able to adjust air flow (oxygen) to compensate for changes in waste composition. Modern facilities also compensate by adjusting the waste fuel feed rate. For example, if too little heat is being produced, more waste can be fed to the incinerator to ensure enough energy is present in the combustion zone. Conversely, if waste with higher energy content enters the furnace, the feed rate can be reduced.

Combustion control is very important to reduce the creation of harmful byproducts (such as CO, TOC and NO_x) as much as possible. Many intermediate steps are involved in the oxidation of long chain hydrocarbons in the combustion gas to products of complete combustion (carbon dioxide and water). By ensuring complete combustion, the creation of unwanted byproducts is minimized and the amount of energy captured from the waste is maximized.

Generally speaking, proper combustion conditions that discourage the generation of unwanted byproducts are those that:

- Ensure that there is complete mixing of the fuel and the air
- Maintain high temperatures in the presence of an adequate amount of oxygen
- Have proper mixing or agitation to prevent the formation of quench zones or low temperature pathways that would allow partially-reacted solids or gases to exit from the combustion chamber.

It is particularly important to prevent the generation of soot in the system because carbon present in the fly ash will lead to increased formation of dioxins and furans. The formation of soot is reduced by following the proper operational controls as discussed above.

The furnace of a typical modern mass burn incineration facility used in the North American market is designed to provide at least a one second retention time at a temperature of approximately 1,000°C in the combustion zone (after the last point of air injection) while processing waste. This has generally been accepted in North American regulations/guidelines as an appropriate requirement. Maintaining 1,000°C for one second in the combustion zone has been recognized by the EU as a condition that can result in internal corrosion, in part as it may cause the fly ash present in the flue gas to melt. The requirements established in the EU are for a minimum two second retention time at 850°C. Both of these temperatures, in combination with the respective retention time, are high enough to ensure the complete destruction of organic substances present in the waste. Even during waste feeding and non-emergency shutdowns, the temperature in the combustion zone is not allowed to fall below 850 – 1,000°C.^[84] Auxiliary burners are used to maintain temperature and residence time in the furnace.

There is merit in considering application of the approach applied in the EU within the BC guideline. At issue is the combustion 'zone' in which the flue gas must be held at or above the required temperature. Generally, this is defined as the last point of air injection (i.e., the over-fire air provided to ensure complete combustion). Depending on the design of the WTE facility, maintaining 1,000°C for one second after this point of air injection may have undesirable consequences. Molten particles within the flue gas can cause fouling and/or corrosion of the heat transfer surfaces for the boiler. Design of the combustion chamber and boiler must address the need to cool the flue gas to approximately 650°C before it reaches the heat transfer surfaces of the boiler. Therefore, some flexibility in specifying the combination of temperature and residence time is necessary to take into account incinerator-specific operational factors.

Several new technologies have been developed to reduce the production of NO_x during combustion by re-circulating part of the flue gas (FGR). These technologies are often applied in Europe. One such technology is Covanta's very low NO_x (VLN™) system. This technology was developed by Martin GmbH in cooperation with partner companies such as Covanta and is described in more detail

⁸⁴ Durham/York Residual Waste Study Environmental Assessment, November 27, 2009, Stantec Consulting Ltd

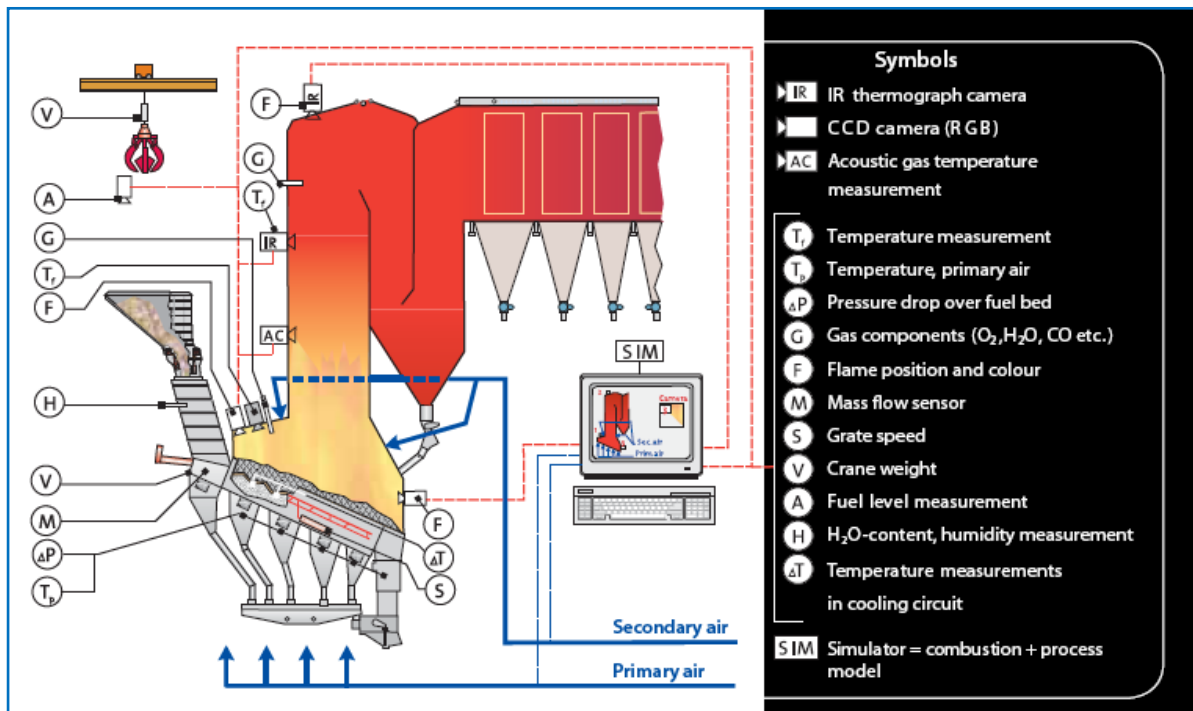
Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 4: Air Emissions Controls

below.^[85] Another NO_x reduction system has been developed by VonRoll/Wheelabrator, called the VLNR (very low NO_x reduction) system. The system is based on injection of ammonia/urea at various levels. The injection of ammonia/urea is strictly controlled in order to ensure reaction at the most optimal time. Other vendors are using the same principle where it is possible to inject ammonia/urea at different levels depending on the optimum temperature but have not promoted their systems under specific trade names.

Figure 4-1 provides a schematic overview of the furnace operational controls typical for a modern mass burn WTE facility.^[86]

Figure 4-1: Control Components of a Modern Furnace Control System



Source: Babcock and Wilcox Volund. 2009. 21st Century Advanced Concept for Waste-Fired Power Plants: A Solution to Asia's Mounting Waste Problems

The following list identifies a number of the advantages associated with the use of proper operational controls during the waste incineration process.^[87]

- Better bottom ash quality (due to sufficient primary air distribution and a better positioning of the incineration process on the grate)
- Less fly ash production (due to less variation in the amount of primary incineration air)

⁸⁵ Martin GmbH für Umwelt- und Energietechnik: http://www.martingmbh.de/index_en.php?level=2&CatID=6.79&inhalt_id=66, 2010

⁸⁶ Babcock and Wilcox Volund. 2009. 21st Century Advanced Concept for Waste-Fired Power Plants: A Solution to Asia's Mounting Waste Problems.

⁸⁷ Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT for the Incineration of Waste.

- Better fly ash quality (less unburned material, due to more stable process conditions in the furnace)
- Less CO and hydrocarbon formation (due to more stable process conditions in the furnace, i.e., no cold spots)
- Less (risk of) formation of dioxin (-precursors) (due to a more stable process in the furnace)
- Better utilization of the plant capacity (because the loss of thermal capacity by variations is reduced)
- Better energy efficiency (because the average amount of incineration air is reduced)
- Better boiler operation (because the temperature is more stable, there are less temperature 'peaks' and thus less risk of corrosion and clogging fly ash formations)
- Better operation of the flue gas treatment system (because the amount and the composition of the flue gas is more stable)
- Less maintenance and better plant availability.

The following subsection provides further details for one example of operational NO_x control that can be applied in North America.

Operational NO_x Control: Example Covanta VLN™

The Covanta VLN™ process utilizes a unique combustion air system design, combined with an advanced combustion monitoring and control system, to achieve substantial reduction in NO_x formation. The VLN™ process, in addition to the conventional primary and secondary air systems, features an internal recirculation gas (IRG) injection system located in the upper furnace. IRG is an internal stream drawn from the rear of the combustor, above the burnout zone of the grate. The distribution of flows between the primary air, secondary air and IRG gas streams is controlled to yield the optimal combustion gas composition and temperature profile to minimize NO_x and control combustion. The control methodology takes into account the heating value of the waste and the fouling condition of the furnace.

Figure 4-2 presents a schematic overview of the Covanta VLN™ Process.

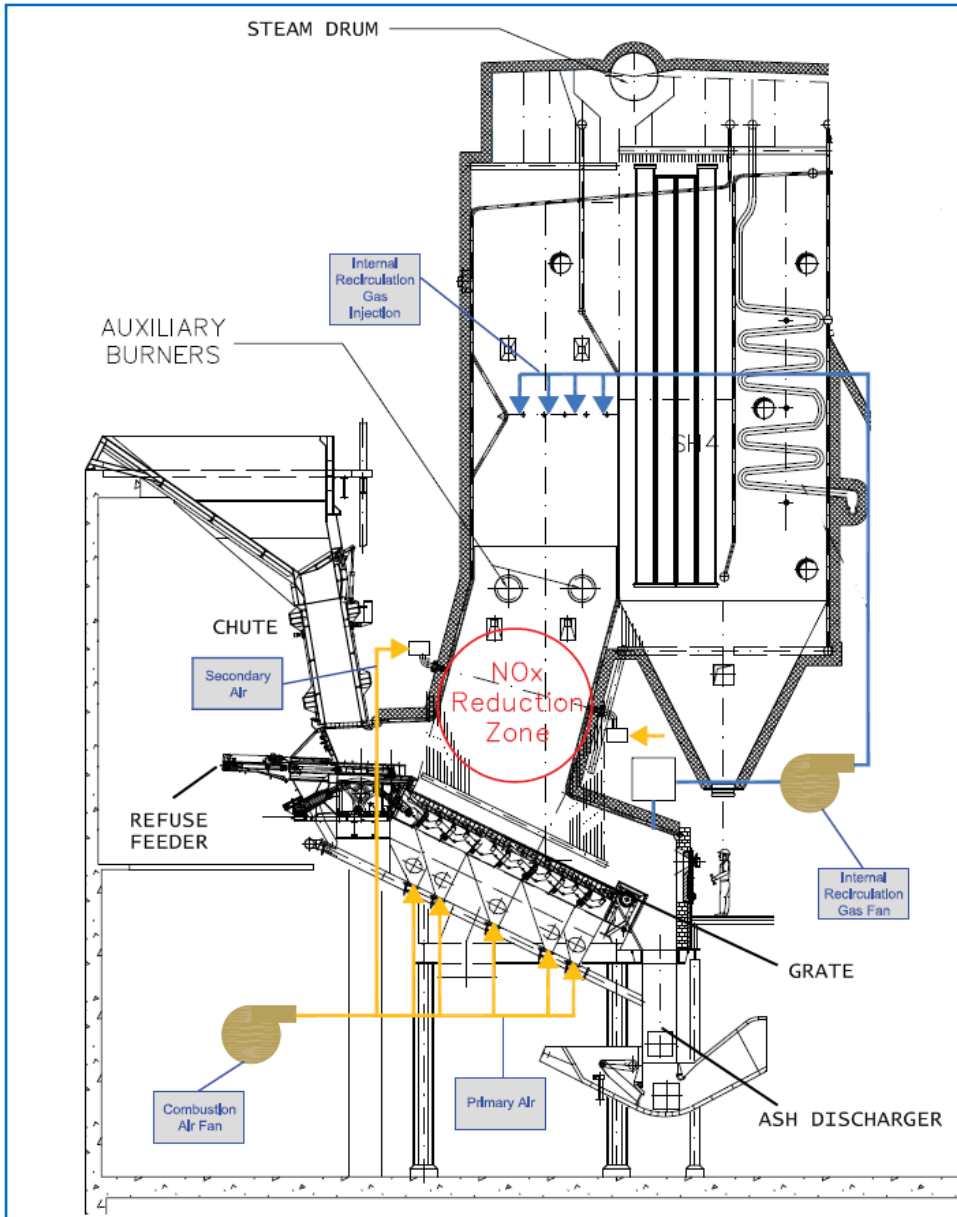
Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 4: Air Emissions Controls

Figure 4-2: Conceptual Schematic Diagram of Covanta VLN™ Process



Source: Durham/York Residual Waste Study Environmental Assessment, November 27, 2009, Stantec Consulting Ltd

4.1.2 Operational Controls for Gasification Systems

As mentioned previously in this report, technologies that gasify MSW are much less proven than conventional combustion technologies. For that reason, information describing the operational controls used by gasification technologies is quite sparse compared to the operational controls used by mass burn incinerators. Further, the operational controls used by a gasification facility will depend

on the specific gasification technology being considered. For instance, the operational controls used in the Nippon Steel gasification process discussed below are different from those used in the Thermoselect process because there are some fundamental differences between the technologies.

The following paragraphs describe the operational controls used by gasification facilities utilizing the Nippon Steel “Direct Melting System” technology. The Japanese Nippon Steel technology is discussed here as it is one of the more commercially proven MSW gasification technologies, as noted in Section 2.2.1.2. As of 2009, Nippon Steel had 28 operational plants in Japan and one in Korea, which together process more than 1.9 million tonnes of MSW, sewage sludge and other residues per year.^[88]

The Nippon Steel “Direct Melting System” operates as follows.^[89] MSW is fed into the top of the furnace (by a crane) with the required amounts of coke and limestone. The waste is charged into the melting furnace when the signal from the burden level meter (installed in the furnace) indicates that the burden level has dropped to the specified level. At the base of the melting furnace, molten materials are discharged into a water granulator and are then separated into slag and metal. The syngas produced is transferred to a combustion chamber. The heat is recovered from the gas via a hot-water generator and then the flue gas is treated by APC equipment before it is released from the stack.

The following list illustrates the digital control systems utilized by the Nippon Steel technology:

- The waste, coke and limestone feed rates and the molten residue generation rate are all measured and recorded to ensure proper feed rates.
- The pressure and temperature in the melting furnace and combustion chamber and the flow rate of air supplied to the melting furnace and combustion chamber are all continually monitored to ensure efficient operation.
- The composition of syngas leaving the melting furnace (CO, CO₂, O₂, CH₄, H₂) and supplied to the combustion chamber, and the composition of the waste gas leaving the combustion chamber (CO₂, O₂, CO, NO_x) are also continuously monitored.

All this data is sent into a distributed control computer and used for real-time analysis of material balance and to ensure the plant is operating at optimal efficiency. Figure 4-3 illustrates the instrumentation system used in one of Nippon Steel’s demonstration plants.^[90] It should be noted that the APC train depicted in the figure is from one of Nippon Steel’s older facilities. Their newer facilities tend to include a bag filter and NO_x reduction system.

⁸⁸ University of California, Riverside. 2009. Evaluation of Emissions from Thermal Conversion Technologies Processing Municipal Solid Waste and Biomass

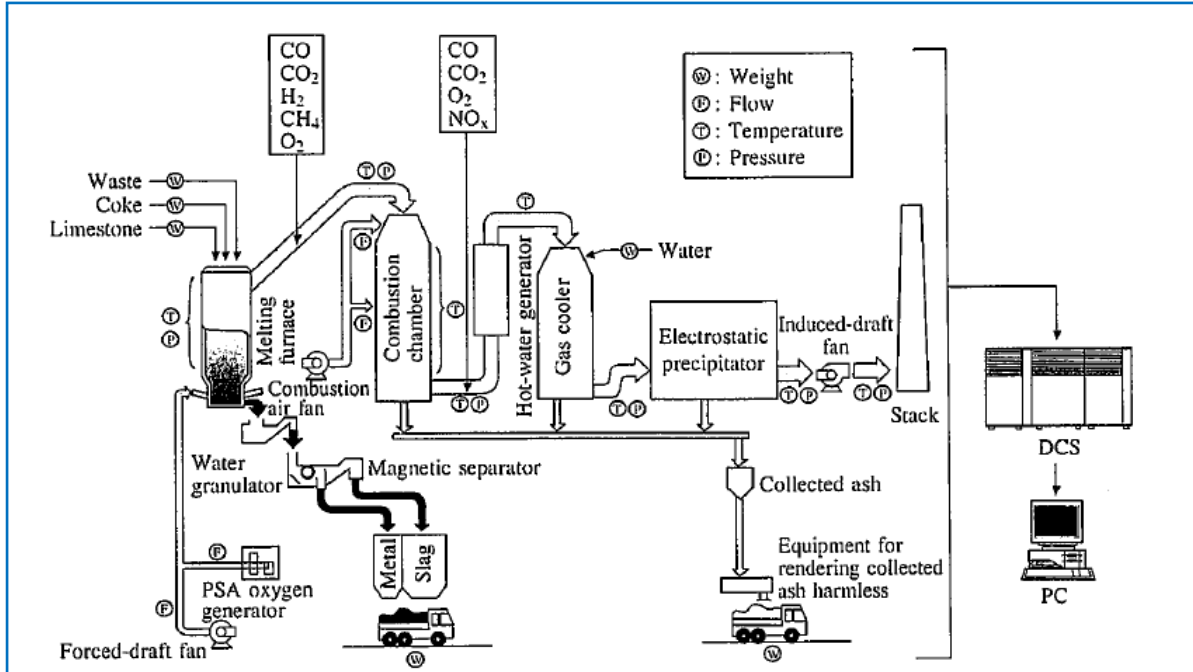
⁸⁹ It should be noted that all Nippon Steel facilities utilize the DMS technology.

⁹⁰ Nippon Steel Technical Report No. 70. July 1996. Research and Development of Direct Melting Process for Municipal Solid Waste

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices
Final Report
Section 4: Air Emissions Controls

Figure 4-3: Conceptual Diagram of Operational Controls Used by Nippon Steel



Source: Nippon Steel Technical Report No. 70. July 1996. Research and Development of Direct Melting Process for Municipal Solid Waste

4.2 Air Pollution Control Systems

WTE facilities convert municipal solid waste into gaseous, liquid and solid conversion products with a simultaneous or subsequent release of heat energy which is captured. Air emissions released from WTE facilities generally arise from the compounds present in the waste stream, and are formed as a normal part of the combustion process.

In order to reduce the environmental impacts associated with WTE facilities air pollution control (APC) systems have been developed. In general, APC systems are used to cool flue gases, scrub acidic gases and capture particulate matter and various contaminants such as heavy metals and trace organics.

Significant improvements have been made in APC systems of WTE incinerators over the past few decades and advancements continue to be made to the types of APC systems used for both MSW and Hazardous Waste incinerators.^[91]

Up to the mid-1960s, waste incineration flue gas treatment was relatively simple. A common method was to cool the flue gas down to a temperature of 250 – 300°C by injecting water (evaporative cooling) and the flue gas was passed through a cyclone to remove fly ash. In the late 1970s and

⁹¹ A.J. Chandler & Associates Ltd.

1980s, semi-dry and wet flue gas treatment systems were developed, followed by systems to address NO_x and dioxins (mainly based on activated carbon) in the late 1980s and 1990s. These systems included the introduction of bag filters for dust removal.^[92]

There are a large number of air pollution control technologies that are currently used by WTE facilities worldwide to control the release of harmful pollutants to the atmosphere. Most of these controls are post-combustion controls, or controls added to the back-end of an incinerator to remove the unwanted byproducts of incineration. The sub-sections below provide an overview of the most common air pollution control technologies and how they act to limit the release of pollutants.

These sub-sections generally describe the primary elements of a conventional APC system, followed by identification of some of the more common APC trains.

4.2.1 Primary Air Pollution Control System Components

This section provides an overview of the primary components that would be included in the APC train for a WTE facility. Further discussion in Section 4.2.2 describes factors and aspects considered to select and combine these various components together within APC trains.

4.2.1.1 Activated Carbon Adsorption (Mercury, Dioxin/Furan Control)

Activated Carbon is used in an APC system to control the release of trace organics (including dioxins/furans) and mercury into the atmosphere. Activated carbon achieves this by adsorbing these chemicals onto its surface.

There are two main types of activated carbon adsorption systems, namely powdered activated carbon (PAC) injection and carbon bed filters (known commercially as activated char reactors (ACR) or absorbers). By far, the most common type used in WTE facilities is PAC injection (six of the seven facilities currently operating in Canada use this form of carbon adsorption).^[93] The following paragraphs present an overview of the two types of systems.

PAC injection systems are used at the back end of WTE facilities as the first step in flue gas treatment following incineration. This is the method that is being considered in the proposed Durham/York incinerator project and is currently used at the Algonquin Power incinerator in the Peel Region.^{[94],[95]} PAC injection systems operate in the following way. Powdered activated carbon is injected into the flue gas prior to a fabric filter baghouse (this will be discussed later) and dioxins/furans and volatilized mercury are adsorbed onto the carbon particles. The particles of activated carbon with adsorbed organic molecules are then captured in the fabric filter baghouse where it forms a cake on the filter's surface allowing for additional adsorption as well as filtering. While PAC injection systems have lower removal efficiency as compared with fixed activated carbon

⁹² Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT For the Incineration of Waste

⁹³ GENIVAR Ontario Inc. in association with Ramboll Danmark A/S, 2007. *Municipal Solid Waste Thermal Treatment in Canada*

⁹⁴ <http://www.peelregion.ca/pw/waste/facilities/algonquin-power.htm#apc>

⁹⁵ Durham/York Residual Waste Study Environmental Assessment, November 27, 2009, Stantec Consulting Ltd

bed filter systems, the injection of powdered activated carbon into the gas stream is a far less expensive method of removing dioxin/furans and mercury from the flue gas.

Fixed activated carbon bed filters can be installed at the end of the APC system to clean gases and remove trace organics and mercury before the flue gas is released into the atmosphere. The carbon bed filter consists of a vertical chamber with a bed depth of typically between 0.5 to 1 m. Carbon bed filters allow for a maximum flue gas velocity of 0.2 m/s and require an operating temperature of between 120 and 150°C to avoid condensation.

Carbon bed systems have the highest known removal efficiency for dioxins and furans (>99.9%) as well as for many other pollutants and are commonly used in Europe, Asia and Australia. The major disadvantage of the carbon filter system is the capital investment and operating costs associated with these systems, as well as the need for proper disposal of spent carbon adsorbent. In Europe, the spent carbon adsorbent is usually combusted in the incinerator. Both PAC injection systems and carbon bed systems can be used to achieve regulatory compliance in the jurisdictions studied within this report, and can achieve compliance with the most stringent of the regulatory limits. As a result, the decision to use either system may often be based on cost, as part of a reasonable BACT assessment process.

4.2.1.2 Fabric Filter Baghouses (Particulate Matter Control)

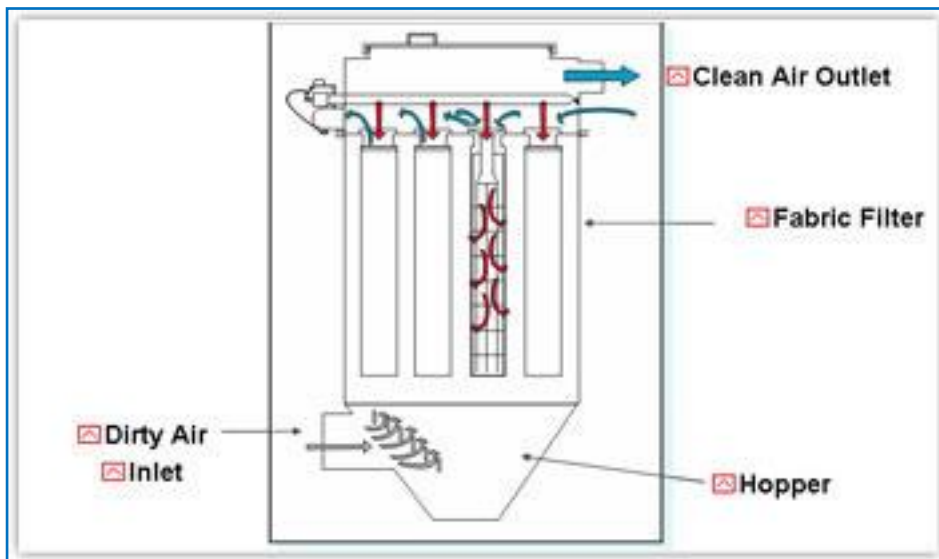
Fabric filter baghouses are used to remove particulate matter from the WTE flue gas before it is released into the atmosphere. Their operation is fairly simple: as flue gases pass through a tightly woven fabric, particulate matter collects on the fabric, preventing it from being released into the atmosphere. The “dust cake” which forms on the surface of the filter due to the collection of particulate matter also helps (up to a point) to increase the filtering efficiency by creating an increased barrier to air movement.

Baghouses are classified based on the method used to clean them. There are two main types of baghouse systems: reverse air baghouses and pulse-jet fabric filters. In a reverse-air baghouse, the flue gas flows upward through the insides of vertical bags which open downward. Fly ash from the flue gas collects on the insides of the bags, and the flow of gas keeps the bags inflated. To clean the bags, a compartment of the baghouse is taken off-line, and the gas flow in this compartment reversed. This causes the bags to collapse, and collected dust to fall from the bags into hoppers. The cleaning cycle in a reverse-air baghouse typically lasts about three minutes per compartment. Because reverse-air cleaning is gentle, reverse-air baghouses typically require a low air-to-cloth ratio.

In a pulse-jet fabric filter, the dirty flue gas air flows from the outside of the bags inward, and the bags are mounted on cages to keep them from collapsing. Dust which collects on the outsides of the bags is removed by a reverse pulse of high-pressure air. This cleaning does not require isolation of the bags from the flue gas flow, and thus may be done on-line. Because pulse-jet cleaning is harsh, the bags remain relatively clean, so that a higher air-to-cloth ratio (i.e., a smaller baghouse as

compared to reverse-air) may be used. Figure 4-4 illustrates a schematic overview of a pulse-jet type fabric filter baghouse.^[96]

Figure 4-4: Schematic Overview of a Pulse-Jet Fabric Filter Baghouse



Source: http://www.neundorfer.com/FileUploads/RichTextboxImages/Image/pulse_jet_baghause.jpg

Baghouse performance is determined by a variety of factors including the fabric chosen, the cleaning frequency and methods, and the particulate characteristics. A number of different fabrics can be used in baghouses. Fabrics can be chosen which will intercept a greater fraction of the particulate. Some fabrics are coated with a membrane with very fine openings for enhanced removal of submicron particulate. However, often these highly efficient fabrics are much more expensive than more conventional materials.

It is important to realize that the particles are not only caught by interception. Electrostatic forces and Brownian movements also play a role, especially for particles that seem to be too small to be caught by the fabric (or the accumulated dust cake). Consequently, baghouse filters have their lowest collection efficiency at a particle size around 0.3 μm . Both smaller (i.e., nanoparticles) and larger particles are more effectively removed.

Baghouses are often capable of 99.9% removal efficiencies. Removal efficiency is relatively level across the particle size range (except at around 0.3 μm), so that excellent control of PM_{10} and $\text{PM}_{2.5}$ can be obtained.^[97]

⁹⁶ http://www.neundorfer.com/FileUploads/RichTextboxImages/Image/pulse_jet_baghause.jpg

⁹⁷ <http://www.icac.com/i4a/pages/index.cfm?pageid=3398>

4.2.1.3 Electrostatic Precipitators (ESP) (Particulate Matter Control)

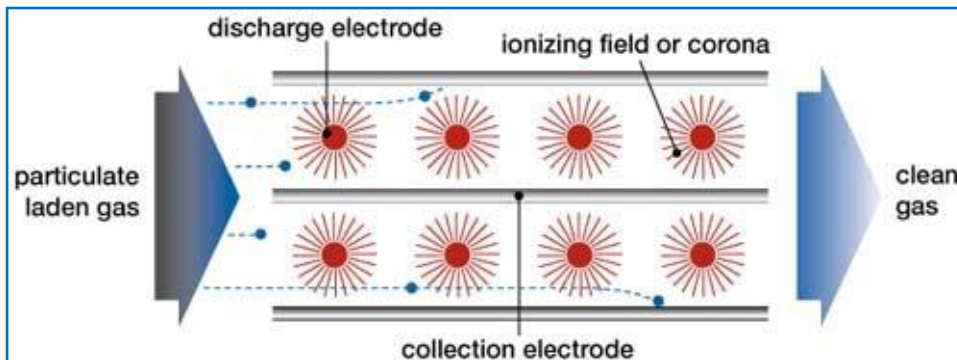
Electrostatic precipitators (ESPs) use electrical fields to remove particulate matter from flue gas. ESPs have been in common use for a long time. Typically, ESPs have low energy requirements and operating costs.

Basically, there are three steps that an ESP uses to remove particulate matter from the flue gas.^[98]

- Particle charging
- Particle collection
- Removal of collected particulate.

In an ESP, an intense electric field is maintained between high-voltage discharge electrodes and grounded collecting electrodes or plates. A corona discharge^[99] from the discharge electrodes ionizes the gas passing through the precipitator, and gas ions subsequently ionize other particles. The electric field drives the negatively charged particles to the collecting electrodes. Periodically, the collecting electrodes are rapped mechanically to dislodge collected particulate, which falls into hoppers for removal. Figure 4-5 provides a conceptual overview of an ESP.^[100]

Figure 4-5: Conceptual Overview of an ESP



Source: <http://web.njit.edu/~avs9/Procedure%20Draft%20Final.htm>

Most precipitators have three to five independent electrical sections in series (referred to as sectionalization). Each independent section removes a fraction of the particulate in the gas stream; this arrangement allows the use of higher voltages in the first sections of the precipitator, where there is more particulate to be removed. Lower voltages must be used in the final, cleaner precipitator sections to avoid excessive sparking between the discharge and collecting electrodes.

⁹⁸ <http://hamon-researchcottrell.com/HRCTechnicalLibrary/Reviving%20an%20Electrostatic%20Precipitator.pdf>

⁹⁹ A corona discharge is an electrical discharge brought on by the ionization of a fluid surrounding a conductor, which occurs when the potential gradient (the strength of the electric field) exceeds a certain value, but conditions are insufficient to cause complete electrical breakdown or arcing.

¹⁰⁰ <http://web.njit.edu/~avs9/Procedure%20Draft%20Final.htm>

Precipitator sectionalization also allows for the collection of particles re-entrained (due to rapping) in the flue gas stream to be collected in downstream sections of the precipitator.

There are several factors which contribute to ESP performance and particle removal efficiency including precipitator size, flow uniformity, re-entrainment, and particle resistivity.

- **Precipitator Size** – determines particle treatment time. The larger (longer) the precipitator the higher chance a particle will be charged and collected.
- **Flow Uniformity** – flow non-uniformity and re-entrainment are factors that decrease precipitator performance. Uniform gas flow ensures that there is no high gas velocity resulting in short treatment time paths through the precipitator. Attaining flow uniformity also minimizes "short circuiting," or gas flows bypassing the electrical fields.
- **Re-entrainment** – re-entrainment of collected particles can occur during rapping (particle collection). The amount of re-entrainment can be reduced through proper rapper design and timing and maintenance of hopper ash levels and flow uniformity.
- **Resistivity** – resistivity is the resistance of particles to the flow of electric current. Particles with resistivity in the range of $10^7 - 10^{10}$ ohm-cm lend themselves to collection by ESPs as they are easy to charge and only lose their charge once they are deposited on the collection electrode. Particles with low resistivity (less than 10^7 ohm-cm) are more difficult to collect using ESP. These particles lose their charge to a collecting electrode so rapidly that they tend not to adhere to the electrode. This results in a high rate of particle loss. High-resistivity particles form ash layers which adhere very strongly to the collecting electrodes which again may lead to injection of positively charged ions into the space between the discharge and collecting electrodes ("back corona"), thus reducing the charge on particles in this space and lowering collection efficiency.

ESPs are capable of removal efficiencies of up to 99.9% with common efficiencies of 99.5%. Precipitators with high overall collection efficiencies will have high collection efficiencies for particles of all sizes, so that excellent control of PM₁₀ and PM_{2.5} will be achieved with well designed and operated electrostatic precipitators. In practice, 97 – 98% of all particulate matter under 5 µm in diameter are removed by ESPs.^[101] That said, similar to baghouse filters, ESPs also have their lowest collection efficiency at a particle size of around 0.3 µm due to electrostatic forces and Brownian movements.

4.2.1.4 Mechanical Collectors (Particulate Matter Control)

Mechanical collectors use mechanical means to remove particulate matter from the flue gas. One of the most common forms of mechanical collection is the cyclone separator. A cyclone separator is a vertical tank with the bottom end tapered into a pipeline and a section of the top open. Using centrifugal force, the cyclone separates larger particles from smaller ones. The efficiency of cyclone separators

¹⁰¹ <http://www.icac.com/i4a/pages/index.cfm?pageid=3398>

Waste to Energy

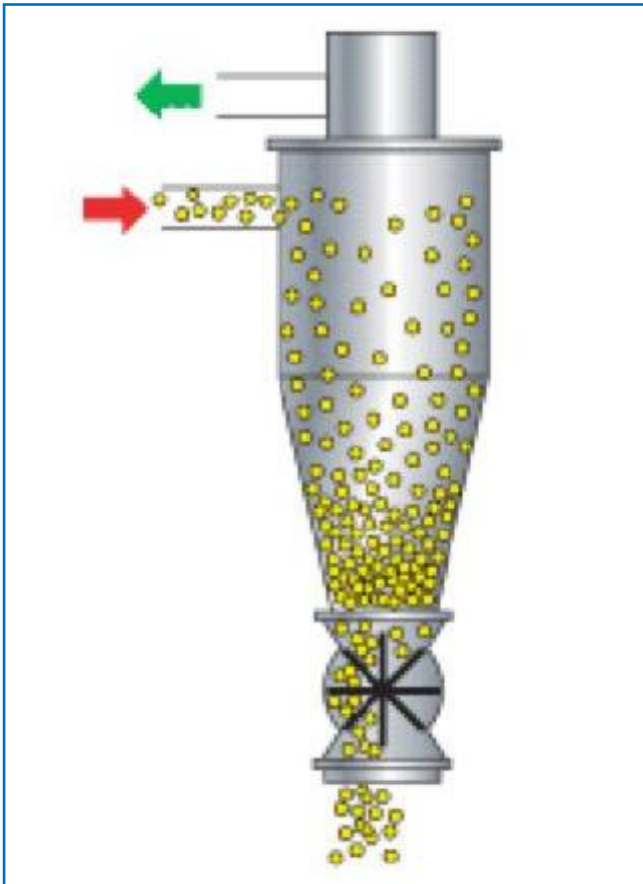
A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 4: Air Emissions Controls

depends largely on flue gas flow vis-à-vis the cyclone diameter: as velocity of the flue gas increases, so does the collection efficiency. Figure 4-6 illustrates the operation of a cyclone separator.^[102]

Figure 4-6: Schematic Overview of Cyclone Separator



Source: http://www.fmdaircontrol.com/cyclone_separators.jpg

Often cyclone separators are combined to increase removal efficiency and are referred to as multiple cyclones. A multiple cyclone consists of an array of cyclones in parallel. Overall, multiple cyclones have removal efficiencies of 70 – 90%. Removal efficiency is largely dependent on particle size; as particle size decreases, removal efficiencies met by the cyclone drop off quickly. The removal of finer particulates such as $PM_{2.5}$ is quite limited. Typically, cyclone removal efficiencies are approximately 90% for particles greater than PM_{10} , 70% for $PM_{2.5}$ and 50% for PM_1 .^[103]

Although multiple cyclones have no moving parts, they require regular cleaning and preventative maintenance to ensure that collection efficiency is maintained.

¹⁰² http://www.fmdaircontrol.com/cyclone_separators.jpg

¹⁰³ <http://www.icac.com/i4a/pages/index.cfm?pageid=3398>

In general, cyclones on their own cannot achieve the emission levels now applied to modern waste incinerators. They can, however, have an important role to play where applied as a pre-duster before other flue gas treatment stages.^[104]

4.2.1.5 Acid Gas Scrubbers (Multi-Pollutant Control)

“Scrubber” is a general term that describes APC devices that use both physical and chemical absorption to remove pollutants from the flue gas stream. Scrubbers, which are generally classified as either “wet” or “dry/semi-dry”, rely on a chemical reaction with a sorbent to remove acidic gases including sulfur dioxide (SO₂), hydrochloric acid (HCl) and hydrofluoric acid (HF) from the flue gas stream. In addition to acidic gases, scrubbers are also capable of removing particulate matter and heavy metals such as mercury.

According to the EPA and others, both wet and dry scrubbers have been shown to reduce HCl emissions by 95% and more, and wet scrubbers have been shown to reduce HF emissions by more than one-third. Others have reported ranges of 87 – 94% removal of HCl and 43 – 97% removal of HF by both wet and dry scrubbers.^[105] The following subsections discuss wet and dry scrubbers separately in more detail.

Wet Scrubbers

In a wet scrubber, the flue gas stream is brought into contact with a scrubbing liquid or sorbent. This is accomplished by various methods including spraying the flue gas with sorbent, forcing it through a pool of liquid or by some other method. The gaseous or particulate pollutants present in the flue gas stream come into direct contact with sorbent and are dissolved or diffused (scrubbed) into the liquid.

The sorbent is typically some kind of alkaline slurry of limestone which reacts with the acidic gases to form neutralized byproducts (i.e., SO₂ reacts to form calcium sulfite or calcium sulfate). The wet solid byproduct which is formed typically requires further treatment (dewatering, precipitation of heavy metals) before it is released from the facility. The dewatered, purified sludge can then be disposed of via other conventional methods and the treated wastewater can leave the site.

Alternatively, instead of using an alkaline sorbent, water can be used as the sorbent in the wet scrubber. When water is used, it mixes with the acidic compounds and increases the PH (reduces the acidity). Water is equally as effective as an alkaline sorbent at capturing particulate matter. A wet scrubber utilizing water requires an additional step which takes the watered solution and treats it with alkaline substances (i.e., limestone) to lower its acidity. This system also results in wastewater which must be treated to remove heavy metals resulting in sludge and a wastewater stream which leaves the site.

Generally, wet scrubbers have relatively small space requirements and require relatively little capital investment (although they tend to be more expensive than dry or semi-dry systems). Wet scrubbers are able to process high temperature, high acidity, and high humidity flue gas streams. Scrubber

¹⁰⁴ European Commission. 2006. Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration

¹⁰⁵ <http://www.icac.com/i4a/pages/index.cfm?pageid=3398>

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 4: Air Emissions Controls

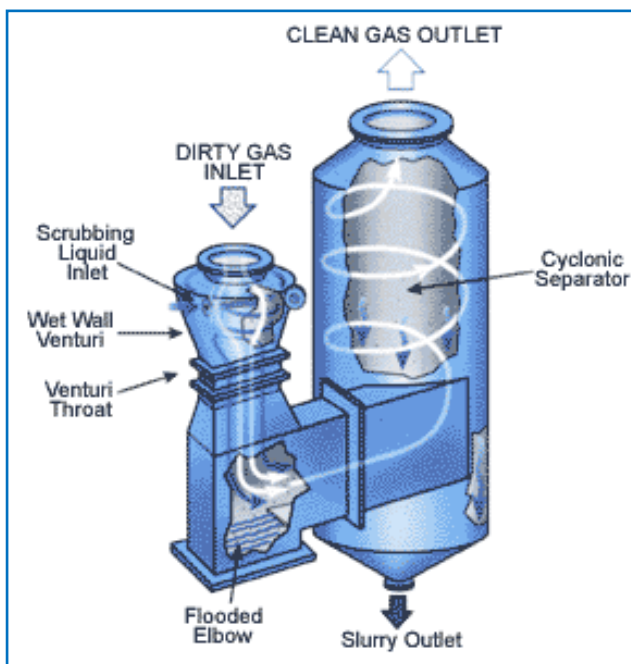
energy requirements have also continued to decrease, helping to lower operating costs. Design and operating parameters relating to the operating efficiency of wet scrubbers include the shape of the scrubber, liquid spray or injection locations, gas residence time, gas velocities, gas and liquid temperatures, gas and liquid pressure drop, and, the liquid/gas flow rate ratio.

Wet scrubbers can achieve high levels of multi-pollutant control, including the control of acidic gases, SO_2 , fine particulates and heavy metals (e.g., cadmium). New wet scrubbers achieve SO_2 removal efficiencies of 95%, with some scrubbers achieving removal efficiencies of up to 99%. In addition, wet scrubbers also provide for significant removal of arsenic, beryllium, cadmium, chromium, lead, manganese, and mercury parameters from flue gas.

As mentioned previously, wet scrubbers are capable of removing a large proportion of particulate matter from the flue gas stream. Venturi scrubbers (a kind of wet scrubber) are commonly used to remove particulate matter from flue gas.

In a venturi scrubber, the “scrubbing” liquid and flue gas are accelerated through a duct which narrows to a small opening and then opens back up. As they reach the small opening, the flue gas and scrubbing liquid are moving at very high velocities which cause the scrubbing liquid to break apart into very fine droplets. These very fine droplets each provide a surface on which particulate matter can be absorbed. Venturi scrubbers are often combined with cyclone separators to remove the water droplets from the flue gas stream. Venturi scrubbers are often capable of removing greater than 90% of particles with diameters above 10 microns. The efficiency of removal for smaller particles is much lower. Figure 4-7 presents a schematic overview of a venturi scrubber.

Figure 4-7: Schematic Overview of a Venturi Scrubber



Source: Mikropul. 2009. Wet Scrubbers

Dry/Semi-Dry Scrubbers

In a dry or semi-dry scrubber, particles of an alkaline sorbent are injected into the flue gas, producing a dry solid by-product. In some cases moisture is added to the sorbent prior to injection (semi-dry scrubber) and in some cases no moisture is added to the sorbent (dry scrubber). If no water is added to the sorbent (dry scrubber), a wet spray humidifier is often placed prior to the dry scrubber in the APC train to humidify the flue gas and to aid in the dry scrubber's operation. Due to the lower levels of moisture used in the dry scrubber, there is no wastewater produced in the dry or semi-dry systems.

Dry/semi-dry scrubber systems can be grouped into three categories: spray dryers (semi-dry), circulating spray dryers (semi-dry), and dry injection systems (dry). All three of these systems offer multi-pollutant control opportunities by combining acid gas, SO₂, particulate, and heavy metal control.

In a spray dryer, alkaline reagent slurry (typically lime based) is atomized into the hot flue gas to absorb pollutants. The resulting dry material, including fly ash, is collected in a downstream particulate control device such as a fabric filter baghouse. Spray dryers commonly are designed for SO₂ removal efficiencies of 70 – 95%.^[106]

A circulating dry scrubber uses an entrained fluidized bed reactor for contacting the reagent, usually hydrated lime, with acid gas and particulate laden flue gas. The fluidized bed promotes an intensive gas-solid mixing that encourages the reaction of acidic gases in the flue gas with the dry lime particles. Similar to spray dryers the mixture of reaction products, unreacted lime, and fly ash is carried to a downstream particulate collector such as a fabric filter baghouse. In a circulating dry scrubber, water spray is introduced into the fluidized bed separately. This enhances the performance of the system by optimizing the surface moisture content of the lime which allows for lesser amounts of lime to be used by the system. Circulating dry scrubbers can provide removal efficiencies of more than 90%.^[107]

¹⁰⁶ <http://www.icac.com/i4a/pages/index.cfm?pageid=3398>

¹⁰⁷ <http://www.icac.com/i4a/pages/index.cfm?pageid=3398>

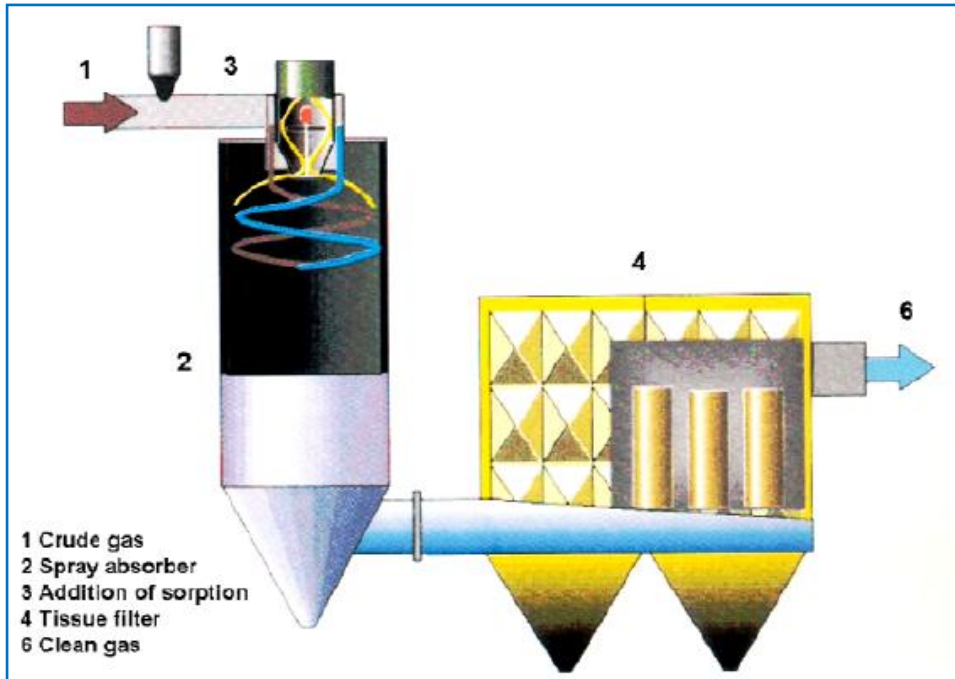
Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 4: Air Emissions Controls

Figure 4-8: Overview of a Circulating Dry Scrubber



Source: European Commission. 2006. *Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration*

Generally, dry/semi-dry scrubbers are simple and have low capital and maintenance costs associated with them. Dry scrubber energy requirements, while less than wet scrubber systems, continue to decrease which helps to lower operating costs.

4.2.1.6 Nitrogen Oxide Control

Selective Catalytic Reduction (SCR) (Nitrogen Oxide Control)

The basic principle of SCR is the reduction of NO_x to N_2 and H_2O . This is accomplished by injecting ammonia (NH_3) into the flue gas stream which then reacts with NO_x gases within a catalyst bed.

The basic operation of an SCR system is quite simple. It consists of a reactor chamber with a catalyst bed, and an ammonia handling and injection system, with the ammonia injected into the flue gas upstream of the catalyst. The system involves no moving parts and other than spent catalyst, the SCR process produces no waste products.

Several different catalysts are available for use at different exhaust gas temperatures. In use the longest and most common are base metal catalysts, which typically contain titanium and vanadium oxides, and which also may contain molybdenum, tungsten, and other elements. Due to the catalyst the reaction can take place at a lower temperature normally around 250°C , however, references to a temperature interval between $180 - 350^\circ\text{C}$ are available.

In principle, SCR can provide reductions in NO_x emissions approaching 100%. In practice, commercial SCR systems have met control targets of over 90% in many cases.

SCR (as opposed to SNCR) is typically used if there is a strict regulatory limit or if a financial incentive to reduce the NO_x emission is introduced. Normally SCR processes achieve emission levels of between 20 – 70 mg/Nm₃.

The SCR process is typically located at the downstream (tail-end) portion of the APC plant where SO₂ and SO₃ levels in the flue gas are reduced to prevent precipitation of ammonia hydrogen sulphate. It also prolongs the lifetime of the catalyst when Hg, HCl and dust are removed.

A disadvantage with the tail-end SCR process is that the flue gas temperature within this portion of the APC train is lower than required, normally around 140 – 150°C, and reheating of the flue gas is necessary. Reheating is normally done through a combination of a heat exchanger where the ingoing flue gas to the SCR-process is preheated by means of the flue gas leaving the SCR and additional heating by approximately 25°C which can be done by the usage of steam from the boiler or the turbine or by means of natural gas/oil.

For the tail-end SCR process, where the concentration of other pollutants in the flue has already been reduced, reactions can be carried out at a lower temperature without incurring too high a risk for precipitation. Some plants have tested SCR at temperatures from 180 – 220°C but the experience is so far not sufficient and the majority of the suppliers still recommend operating temperatures of around 250°C.

Alternatively the SCR process can be placed before the flue gas treatment plant. To have a sufficiently high temperature without needing reheating of the flue gas, the most advantageous placement is at the outlet of the boiler and before the economizer. Due to the high sulphur content the temperature in the SCR process has to be approximately 280°C to prevent precipitation. The experience with high dust catalysts is very limited, and the few plants with high dust SCR system have experienced problems.

If considerations are taken during the design of the catalyst, SCR can absorb dioxin as well. The adsorption of dioxin is dependent on the chemical composition of the catalyst as well as the size of the catalyst.

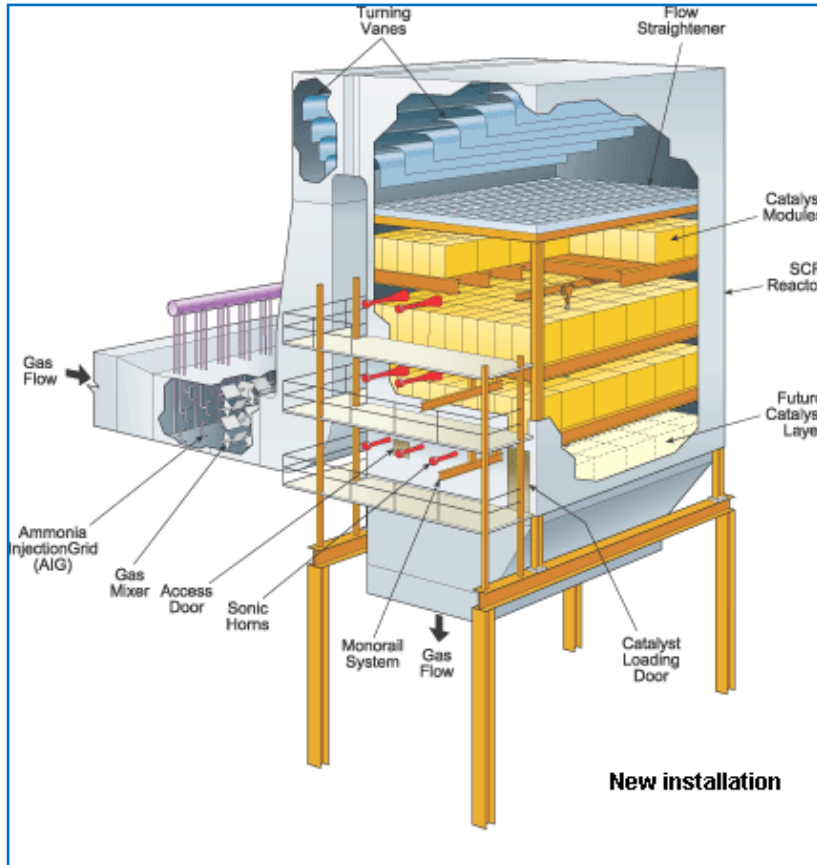
Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 4: Air Emissions Controls

Figure 4-9: Diagram of a Selective Catalytic Reducer



Source: The Babcock and Wilcox Company. 2010. Environmental Equipment: Selective Catalytic Reduction (SCR) System. http://www.babcock.com/products/environmental_equipment/scr.html

Selective Non-Catalytic Reduction (SNCR) (Nitrogen Oxide Control)

Similar to SCR, SNCR is a chemical process that converts NO_x into N_2 and H_2O using ammonia (NH_3). At suitably high temperatures ($870 - 1,150^\circ\text{C}$), the desired chemical reactions occur.

The operation of an SNCR system is quite simple. Ammonia (or urea) is injected/sprayed into and mixed with the hot flue gas. The ammonia or urea then reacts with the NO_x in the flue gas stream, converting it into nitrogen and water vapour. The main difference from SCR is that SNCR does not utilize a catalyst. SNCR is "selective" in that the reagent reacts primarily with NO_x , and not with oxygen or other major components of the flue gas.

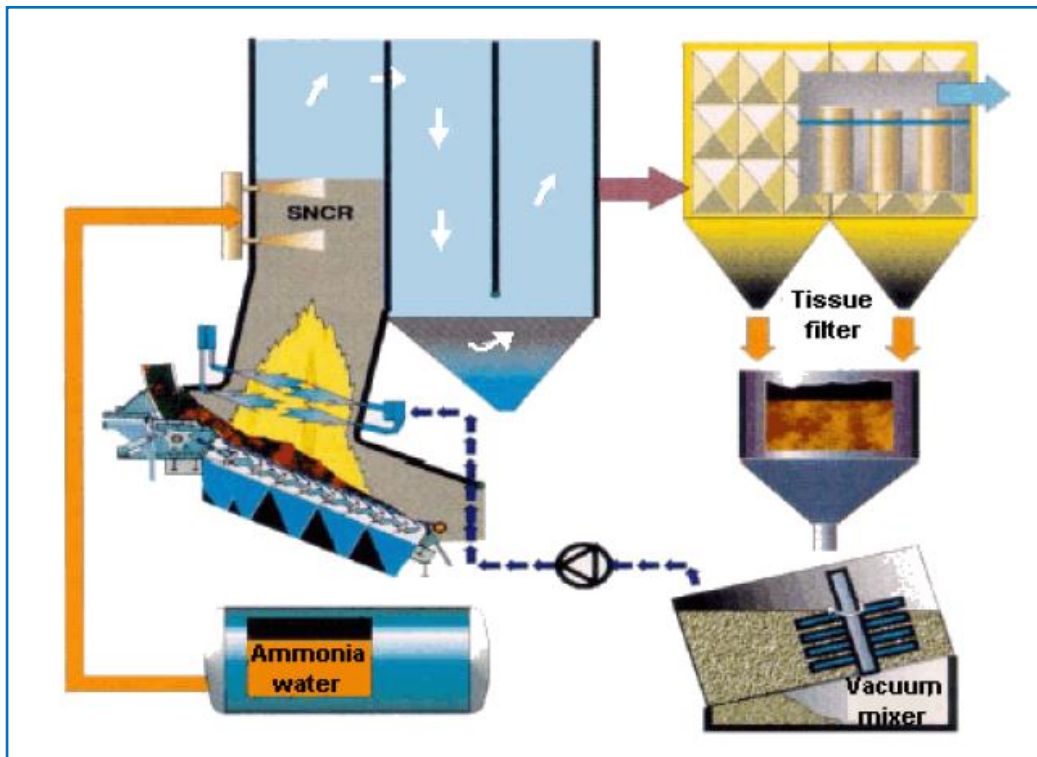
The principal components of an SNCR system are the reagent storage and injection systems, which includes tanks, pumps, injectors, and associated controls, and often NO_x continuous emissions monitors (CEMs). Given the simplicity of these components, installation of SNCR is easy relative to the installation of other NO_x control technologies. SNCR retrofits typically do not require extended source shutdowns.

While SNCR performance is specific to each unique application, NO_x reduction levels ranging from 30% to over 75% have been reported. Temperature, residence time, reagent injection rate, reagent-flue gas mixing, and uncontrolled NO_x levels are important in determining the effectiveness of SNCR.

Emission values around 150 mg/Nm^3 are common for the SNCR process. Lower values – to around 100 mg/Nm^3 – are possible with the SNCR process but the consumption of ammonia is relative high and the risk for ammonia slip will increase.

The ammonia slip is normally limited to $5 - 10 \text{ mg/Nm}^3$ as ammonia may result in a light odour of the flue gas residues.

Figure 4-10: Overview of SNCR System



Source: European Commission. 2006. Integrated Pollution Prevention and Control Reference Document on Best Available Techniques for Waste Incineration

4.2.1.7 Conditioning Towers or Wet Spray Humidifiers

Some WTE facilities utilize a conditioning tower or wet spray humidifier as part of their APC equipment. A conditioning tower consists of a vertical tower where water is sprayed into the gas stream, humidifying the gas stream while decreasing the temperature to about $160 - 185^\circ\text{C}$.

With current APC design, conditioning towers are often used to cool the flue gases prior to the inlet of the baghouse filter at the end of the APC train, in order to protect the baghouse filters and to ensure the optimal temperature range for chemical reactions with lime.

Conditioning towers/humidifiers can be used to reduce gas temperature and elevate humidity to allow for a more effective operation of other downstream APC equipment such as dry acid gas scrubbers. Conditioning towers can also decrease the potential for dioxin and furan formation by dropping flue gas temperatures rapidly below the temperature range for de novo synthesis.

4.2.2 APC System Design and Operation

The individual components of an APC system are combined into APC trains to provide an effective overall system for the treatment of pollutants that are found in the flue gases. There are several common APC trains currently used at operating WTE facilities, to control the release of unwanted pollutants into the atmosphere. The selection of an air pollution control train for a WTE facility depends on a number of factors, such as the desired emissions reductions necessary to meet applicable regulations, the ability of various APC components to function with one another (not all APC equipment is compatible) and the cost of the equipment (capital and operating).

Generally speaking, when choosing an APC train for a WTE facility the first thing considered is how to control the release of acid gases such as SO₂, HCl and HF. After an appropriate control for acid gases is chosen, compatible and appropriate components can be selected for the control of particulate matter, dioxins, mercury and NO_x. In other words, the selection of the APC component to treat acid gases forms the backbone of the APC train and affects the type and placement of other APC controls that manage the release of other chemicals of concern.

There are three main types of treatment systems that treat acidic compounds, and thus three main types of APC trains that are built around the acid gas control measures:

- Dry/semi-dry systems
- Wet systems
- Semi-wet systems (combination of dry/semi-dry and wet systems).

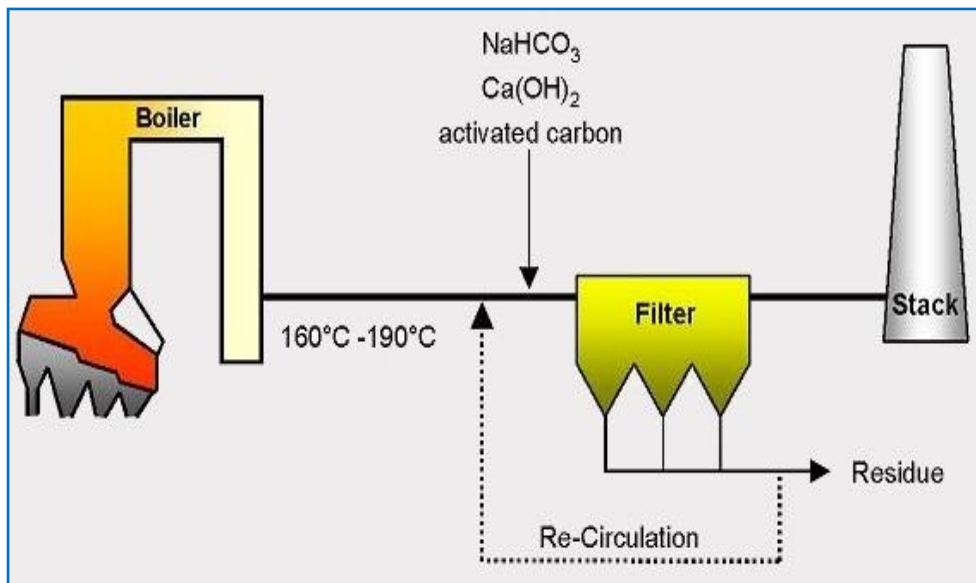
The most common form of APC system currently used by WTE facilities in Canada is the dry/semi-dry system.^[108] The following sections provide an overview of each of these systems.

¹⁰⁸ GENIVAR Ontario Inc. in association with Ramboll Danmark A/S, 2007. Municipal Solid Waste Thermal Treatment in Canada

4.2.2.1 Dry/Semi-Dry Systems

As discussed previously, dry/semi-dry systems for acid gas control^[109] can be grouped into three categories: spray dryers (semi-dry)^[110] circulating spray dryers (semi-dry), and dry injection systems (dry), but the basic operation of each system is similar. In each system, the acidic compounds in the flue gas react in a vessel with a sorption agent (normally calcium hydroxide ($\text{Ca}(\text{OH})_2$) for the dry system and lime milk (a suspension of calcium hydroxide) in the semi-dry system. Alternatively dry sodium bicarbonate (NaHCO_3) can be used as the sorption agent. In dry systems, wet spray humidifiers are often added to the front of the APC train to assist in the operation. Figure 4-11 presents a simple schematic overview of a Dry/Semi-Dry APC system.

Figure 4-11: Schematic Overview of a Dry/Semi-Dry APC System



Source: Fisica Babcock Environment GmbH. 2007. Wet Scrubbing. Accessed March 15, 2010 from <http://www.fisia-babcock.com/index.php?id=183>

The injected sorption agent reacts with the acidic compounds converting them into solid compounds ($\text{HCl} \rightarrow \text{CaCl}_2$, $\text{HF} \rightarrow \text{CaF}_2$, $\text{SO}_2 \rightarrow \text{CaSO}_3$ or CaSO_4). The solid by-products formed are removed later on in the APC train in a fabric filter baghouse or other dust collecting device such as an ESP. By this process, the majority of the acidic compounds present in the flue gas are neutralized and prevented from being released into the atmosphere.

In addition to the adsorption of acidic compounds the dry/semi-dry system also assists in the reduction of other harmful pollutants including particulate matter and heavy metals.

¹⁰⁹ Ramboll

¹¹⁰ Spray dryers followed by fabric filters have become the norm for WTE facilities in the United States (Air Pollution Control For Waste to Energy Plants – What Do We Do Now?, 1997)

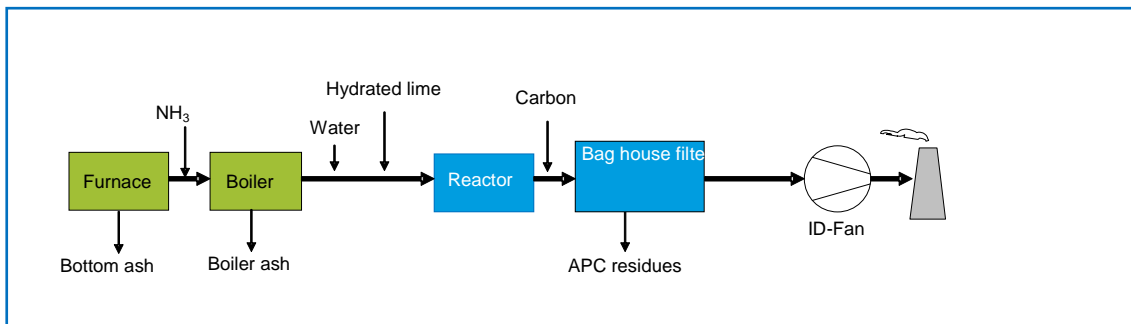
Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 4: Air Emissions Controls

In the dry/semi-dry system, other APC components can then be added to the APC train to assist in the reduction of dioxin/furans, mercury and NO_x emissions. Normally, an activated carbon injection system is added after the acidic gas reactor to adsorb both mercury and dioxins which are then captured in the fabric filter baghouse preventing them from being released into the atmosphere. The last step would be adding a SCR or SNCR APC component, respectively to reduce NO_x emissions.

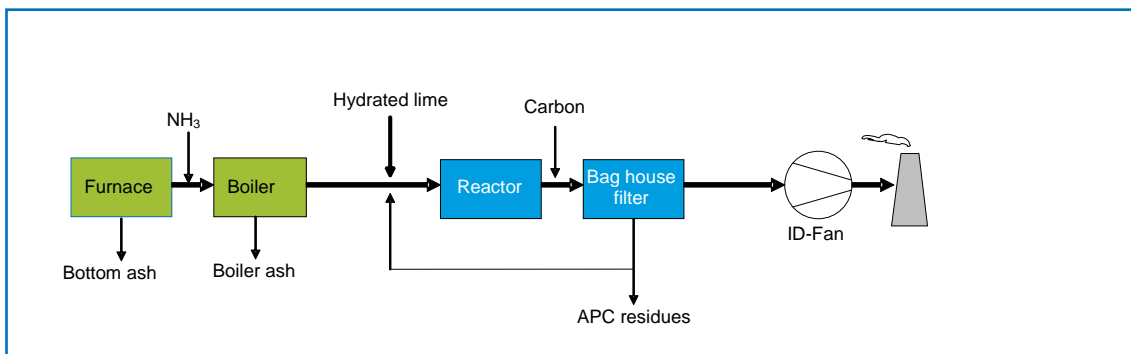
Figures 4-12 to 4-14, below provide an overview of three types of common dry/semi dry APC trains and the combination of key APC components compatible with dry/semi dry acid gas control.

Figure 4-12: Dry APC System



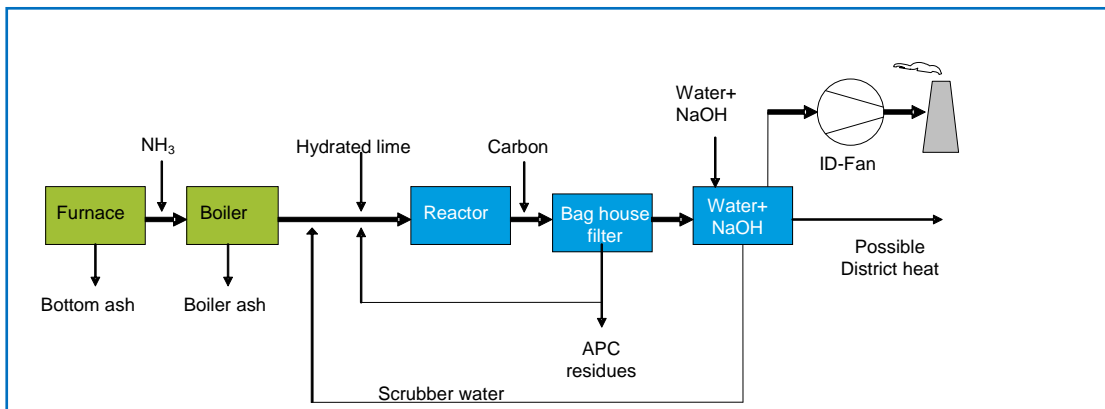
This system includes SNCR for NO_x control, a dry scrubber, use of activated carbon injection to control dioxins/furans and mercury, and a bag house to control particulate and the majority of heavy metals.

Figure 4-13: Semi-Dry System, Example 1



This system includes SNCR for NO_x control, a dry scrubber with recirculation of recovered water from APC residue treatment for humidification, use of activated carbon injection to control dioxins/furans and mercury, and a bag house to control particulate and the majority of heavy metals.

Figure 4-14: Semi-Dry System, Example 2

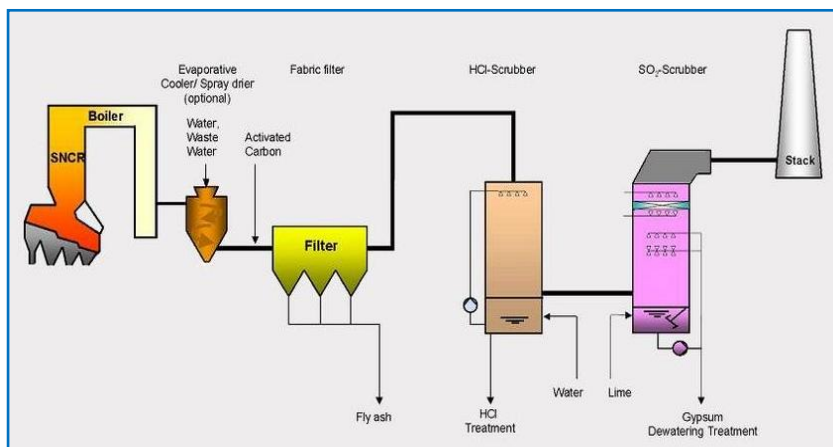


4.2.2.2 Wet Systems

Of all three flue gas treatment methods, the wet system is the only one which generates wastewater to be discharged and based upon our research is the least common type of APC train used in WTE facilities in North America. That said, the wet system is often used in Europe where additional incentives are in place to reduce emissions to air and as up until recently, wet systems were typically able to reduce emissions to a greater degree than dry/semi-dry systems.

Wet systems can be grouped into numerous different categories based upon their geometric shape and method for gas-liquid interaction including packed-bed, counter-flow, cross-flow, bubble-plate, open spray (single and double loop) tower, dual-flow tray, cyclonic, etc. Generally speaking, however, they all function in a similar manner. Figure 4-15 provides a general schematic overview of a wet APC system.

Figure 4-15: Schematic Overview of a Wet APC System



Source: Fisia Babcock Environment GmbH. 2007. Wet Scrubbing. Accessed March 15, 2010 from <http://www.fisia-babcock.com/index.php?id=183>

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 4: Air Emissions Controls

The first stage in a wet system is normally the removal of dust and particulate matter from the flue gas with either an ESP or fabric filter baghouse prior to the wet scrubber. This filtration helps to remove some particulate matter and reduce the concentration of heavy metals in the flue gas. In the next treatment stage in the wet system, the acidic compounds present in the flue gas are washed with water in an “acid scrubber” which produces a wastewater stream. Washing the flue gas with water removes the majority of HCl as it becomes a diluted hydrochloric acid solution. The liquid effluent from the water washing is then passed on to a wastewater treatment stage (to neutralize the acid and to remove heavy metals which may still be present in high concentrations).

The flue gas moves on to an “alkaline” scrubber, in which it is washed with a solution of either sodium hydroxide or a suspension of limestone which removes the majority of SO₂ from the flue gas. The waste liquid remaining after the alkaline scrubber is also sent to wastewater treatment prior to being released from the facility.

After both scrubbing stages, the flue gases are then treated with activated carbon injection to remove the remaining dioxins/furans and mercury. The activated carbon with adsorbed material is then captured in a downstream fabric filter baghouse.

The wastewater from the acid and alkaline scrubbers is normally neutralized to approximately pH 9 by CaCO₃ and NaOH. The heavy metals and other solids present in the wastewater are then precipitated out by the addition of chemicals such as CaCl₂, NaOH, FeCl₃ and TMT 15. The precipitates are dewatered in a filter press before proper disposal while the treated wastewater is discharged from the facility. Similar to dry/semi-dry systems, wet systems also assists in the reduction of other harmful pollutants including particulate matter and heavy metals. Figures 4-16 to 4-18, below, provide examples of typical wet APC systems.

Figure 4-16: Wet APC System, (a)

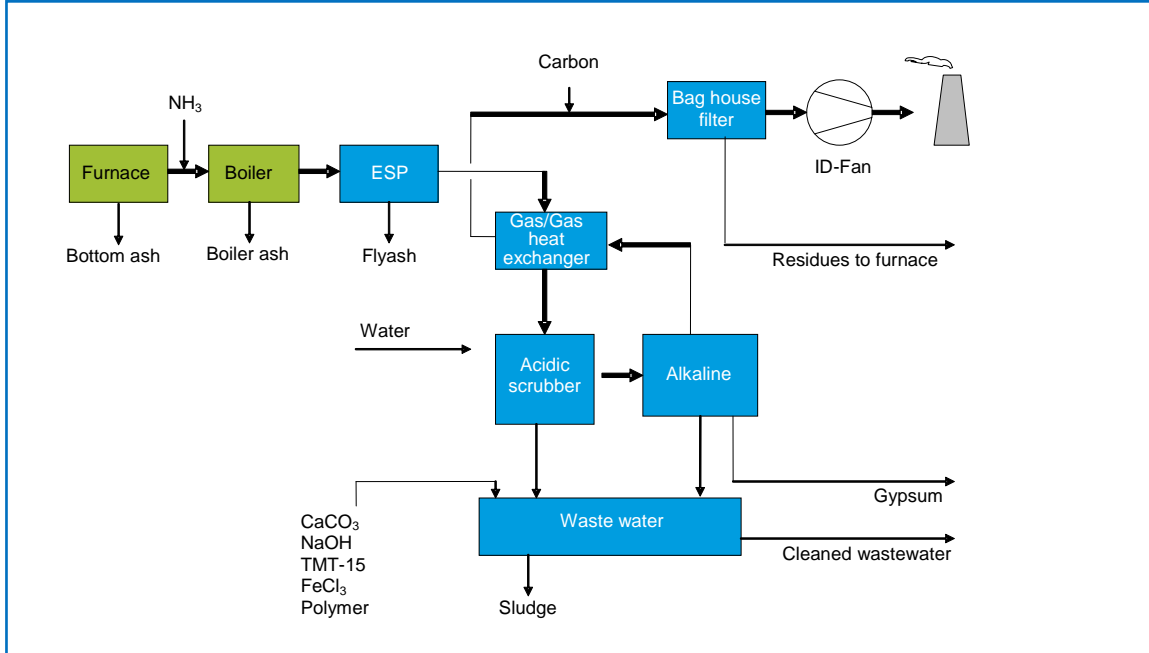
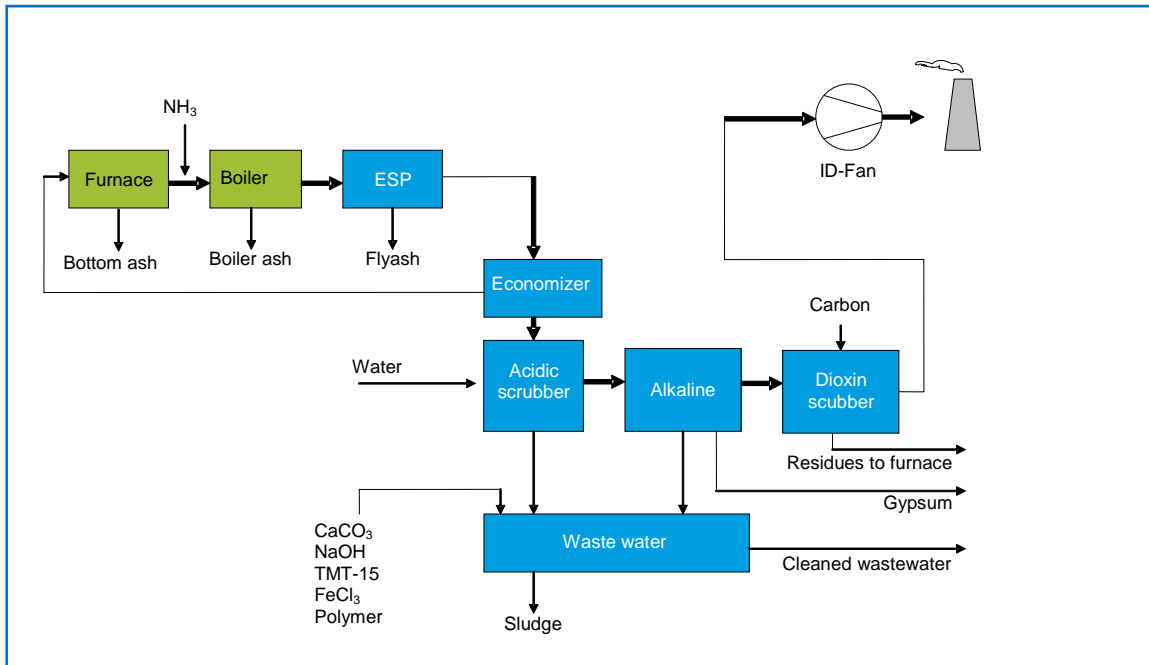


Figure 4-17: Wet APC System, (b)



The diagram illustrates the integrated process flow of a waste-to-energy plant. Key components and their functions are as follows:

- Furnace:** Processes waste, producing **Bottom ash** and sending material to the **Boiler**.
- Boiler:** Generates **Boiler ash** and provides heat to the **Economizer** and **Gas/Gas heat exchanger**.
- Bag house filter:** Filters exhaust from the boiler, producing **Flyash** and sending gas to the **Economizer**.
- Economizer:** Preheats feedwater using boiler and baghouse filter exhaust, then feeds into the **Acidic scrubber**.
- Acidic scrubber:** Removes acidic pollutants using **Water** and feeds into the **Alkaline** unit.
- Alkaline:** Removes alkaline pollutants, receiving inputs from the **Acidic scrubber** and **Waste water** treatment. It produces **Gypsum** and feeds into the **ID-Fan**.
- ID-Fan:** Induced draft fan that moves gas through the **Gas/Gas heat exchanger**.
- Gas/Gas heat exchanger:** Recovers heat from exhaust gas, preheating gas for the **Condensing scrubber** and feedwater for the **Steam heat exchanger**.
- Condensing scrubber:** Removes particulates and soluble gases, producing **Water to scrubber** and sending gas to the **SCR catalyst**.
- SCR (catalyst):** Reduces nitrogen oxides before the gas is released into the atmosphere.
- Steam heat exchanger:** Produces **Drum steam** from feedwater, which is then used as **Condensate to feedwater**.
- Waste water treatment:** Treats wastewater using **CaCO₃**, **NaOH**, **TMT-15**, **FeCl₃**, and **Polymer**. It produces **Sludge** and **Cleaned wastewater**, which is recycled into the **Acidic scrubber** and **Alkaline** units.

Semi-wet systems are basically a combination of semi-dry and wet systems. The semi-wet system combines the semi-dry system with a polishing wet stage in such a way that the water from the wet stage can be used in the preparation of the lime suspension for the semi-dry treatment. Because of this, the semi-wet system is wastewater-free. By adding NaOH to the water in the wet stage the removal efficiency is increased and the production of solid residue decreased correspondingly.

Table 4-1 illustrates the relative advantages and disadvantages of the dry/semi-dry, wet, and semi-wet Systems. As mentioned previously, based upon our research the majority of current WTE facilities in Canada utilize a dry/semi dry APC system while wet systems are more common in the EU.

Table 4-1: Advantages and Disadvantages Associated with Dry/Semi Dry, Wet, and Semi-Wet Flue Gas Treatment Systems

	Dry/Semi Dry System	Wet System	Semi-Wet System
Advantages	<ul style="list-style-type: none"> ▪ Simple technology ▪ No wastewater ▪ Relatively low capital costs ▪ Requires less space than a wet system 	<ul style="list-style-type: none"> ▪ High efficiency ▪ Small amount of solid residue ▪ Possible destruction of dioxins in the furnace ▪ Generally large margin to limit values ▪ Little sensitivity to HCl and SO₂ peaks in the flue gas ▪ Relatively low operational costs 	<ul style="list-style-type: none"> ▪ Generally large margin to limit values ▪ Less sensitive of HCl and SO₂ peaks in flue gas than Dry/Semi Dry System ▪ Lower capital costs than wet system ▪ No wastewater ▪ Less space requirements than Wet System
Disadvantages	<ul style="list-style-type: none"> ▪ Uses large quantities of lime and thereby has high operational costs ▪ Large amount of solid residue ▪ Dioxins in the solid residue ▪ Often little margin to the limit values ▪ Consumption of lime and amount of solid residues are sensitive to high content of HCl and SO₂ in the flue gas 	<ul style="list-style-type: none"> ▪ Many process stage ▪ Production of wastewater ▪ Relatively high capital costs ▪ Requires more space than a dry/semi-dry system 	<ul style="list-style-type: none"> ▪ More expensive than dry/semi-dry system ▪ Medium amount of solid residue

4.2.2.4 NO_x Control System Components

After the acidic gas control system has been selected, the type of NO_x control is determined. As discussed previously, there are two types of NO_x control systems normally used in WTE facility APC trains. Namely, these are Selective Catalytic Reduction (SCR) and Selective Non-Catalytic Reduction (SNCR). Both NO_x control systems are currently in use in Canada, for example the Greater Vancouver Regional District Waste to Energy Facility utilizes SNCR while the Algonquin Power Peel Energy-From-Waste Facility utilizes SCR.^[111]

In state-of-the-art WTE facilities, sophisticated control systems have been developed that greatly reduce the production of NO_x during regular combustion. However, these control systems are usually not able to reduce NO_x emissions to below applicable regulatory limits and thus additional NO_x controls must be put in place.

¹¹¹ GENIVAR Ontario Inc. in association with Ramboll Danmark A/S, 2007. Municipal Solid Waste Thermal Treatment in Canada

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 4: Air Emissions Controls

In SNCR, ammonia is injected into the flue gas stream directly in the furnace at the location where the temperature is around 850°C.

In SCR, the reaction between NO_x and ammonia takes place in a catalytic bed at temperatures normally between 200 and 250°C. In SCR, the catalytic bed is often the last treatment step in the APC train (final treatment device) as dust and SO₂ greatly decrease the lifespan of the catalytic surface. Because of this, the flue gas is often at too low a temperature for the catalytic reaction to take place, requiring the flue gas to be preheated prior to the SCR. Often the incoming flue gas into the SCR system is preheated by the flue gas leaving the SCR which reduces the need for additional heating (which can be done with high pressured steam or natural gas). The consumption of ammonia for an SCR system is normally 1.5 kg 25% NH₃ per kg of NO_x.

The types and choice of Denox currently being used in Europe include both SNCR and SCR, with the choice of system being based both on regulatory requirements and economics. For example:

- In Denmark all Denox systems are based on the SNCR technology as the emission limit of 200 mg/Nm³ can be met with such systems. A NO_x tax has recently been implemented but given the current low level of the tax there is no incentive for further reductions in NO_x emissions.
- In Sweden a high NO_x tax has increased the feasibility of SCR such that most of the new WTE plants are equipped with SCR systems which operate with very low emission levels – often below 20 mg/Nm³.
- In Norway (not member of EU) the regulation can be fulfilled with SNCR but a tax on NO_x based on the size of the WTE facility make the choice of SNCR or SCR comparable.
- Austria has implemented a NO_x emission limit at 70 mg/Nm³ compared to the 200 mg/Nm³ in EU WID and thus in order to meet this limit, SCR systems have been used for many years. The plant in Vienna, Spittelau, has had SCR for close to 20 years. The experience with the catalyst itself is good, however, the design of the preheat-system as well as the possibility for manual inspection and cleaning of the catalyst is not optimal. For new SCR-systems these problems have been addressed and new installations operate satisfactory.
- In Germany the 200 mg/Nm³ emission limit for NO_x was introduced by the national regulation before the EU-regulation was implemented. Many of the German plants are equipped with SCR and have significant operational experience. Some of the older plants have experienced clogging problems. Clogging problems refer to the SCR catalyst being blocked by the chemical reaction products which is mainly due to the design of the catalyst itself because awareness concerning the SO₂ content of the flue gas was not known when initially designing these facilities. For new facilities the reliability of the SCR is high.
- In Italy most WTE plants use SNCR processes. ASM Brescia has experienced good operation and very low emission levels with SNCR. However, the Italian regulation is becoming more stringent especially in the northern part of Italy and ASM Brescia is testing a catalyst system at present.

- Switzerland (not a member of EU) has, like Austria, introduced a NO_x emission limit of 80 mg/Nm³. Most of the WTE facilities in Switzerland are equipped with SCR and have experienced good operation. The SCR is commonly a tail-end solution. One of the Swiss suppliers has good experience from operation of high temperature-low dust SCR solutions.
- In France and Belgium both SNCR and SCR processes are installed.
- In the Netherlands the emission limit is 70 mg/Nm³ and due to that most of the WTE facilities, and all new facilities, are equipped with SCR.

Summary of NO_x Control Systems

The following table (Table 4-2) illustrates the advantages and disadvantages of SNCR and SCR.

Table 4-2: Advantages and Disadvantages Associated with SNCR and SCR

	SNCR	SCR
Advantages	<ul style="list-style-type: none"> ▪ Simple technology ▪ Low capital costs 	<ul style="list-style-type: none"> ▪ Lower consumption of ammonia ▪ Lower emissions possible (10 mg NO_x/m³ can be obtained if enough NH₃ is added)
Disadvantages	<ul style="list-style-type: none"> ▪ Consumes about 30% more ammonia than SCR ▪ Small quantities of ammonia can slip through and pollute the solid residue in dry/semi-dry systems or the wastewater of the wet systems ▪ Typically, vendors may guarantee limits between 100 to 150 mg NO_x/m³ 	<ul style="list-style-type: none"> ▪ High capital costs

4.2.2.5 Mercury and Dioxin/Furan Control System Components

The release of mercury and dioxins/furans from WTE facilities is normally reduced via an activated carbon injection system. Basically, the gaseous mercury and dioxin/furan compounds are adsorbed onto the surface of the activated carbon particles which are later collected in a fabric filter baghouse. This type of control system is capable of removing mercury and dioxin/furans from the flue gas to below regulatory concentration limits. The dioxin filter can either be wet or dry. The dry system is the most commonly used.

4.2.2.6 Trace Heavy Metal Control System Components

The concentration of heavy metals released from WTE facilities is reduced by more than one component of the APC train. In other words, heavy metal control is not specifically associated with any one APC component.

For example, acid gas scrubbers are typically quite efficient in removing large quantities of heavy metals from the flue gas even though this is not their primary purpose. Specifically, wet scrubbers can provide for the significant removal of arsenic, beryllium, cadmium, chromium, lead, manganese and mercury from the flue gas.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 4: Air Emissions Controls

ESPs and fabric filter baghouses also play an important role in the reduction of heavy metals in the flue gas. They accomplish this because volatilized heavy metals often bind to fly ash particles in the flue gas and large quantities of this particulate matter are captured in an ESP or a fabric filter baghouse. In this way, by removing the particulate matter, large quantities of heavy metals are also captured.

Activated carbon is reported to be also used for reducing heavy metals emissions.^[112]

The control of specific heavy metals depends on their distinctive physical and chemical characteristics. For example, mercury is a unique heavy metal in that it vapourizes at a fairly low temperature (357°C) in comparison to other heavy metals. Mercury remains in a gaseous state after passing through the furnace and boiler and its removal from the flue gas depends largely on the speciation of mercury in the flue gas. The speciation of mercury depends on a number of factors such as the amount of mercury present in the waste and the chlorine content of the waste.

At higher chlorine contents (MSW usually contains a sufficient quantity) mercury will be primarily in an ionic form which can be removed by acid gas scrubbers. Metallic mercury (on the other hand) is much harder to control because it is very insoluble in water. Metallic mercury is normally controlled by being transformed into ionic mercury (by adding oxidants) so that it can then be captured by the wet scrubber; or by direct deposition on activated carbon and captured in a downstream ESP or fabric filter baghouse. A small amount of mercury is released into the atmosphere in a vaporous state during the combustion process, while the majority ends up in the APC residue after treatment. Very little mercury ends up in the bottom ash.

Other heavy metals (e.g., arsenic, beryllium, cadmium, lead, manganese etc.) are converted mainly into non-volatile oxides during the incineration process and bind to particulate matter in the flue gas and are then captured by ESPs and fabric filters (some are also captured by activated carbon). The majority of these heavy metals end up in the APC residue after treatment. Typically, a lesser amount of these heavy metals remain in the bottom ash (although for some there is a fairly even distribution between the bottom ash and APC residue).^[113]

4.2.2.7 Particulate Matter Control System Components

As discussed in detail in Section 4.1, particulate matter control is achieved using an electrostatic precipitator or a fabric filter baghouse.

4.2.2.8 Other APC Systems

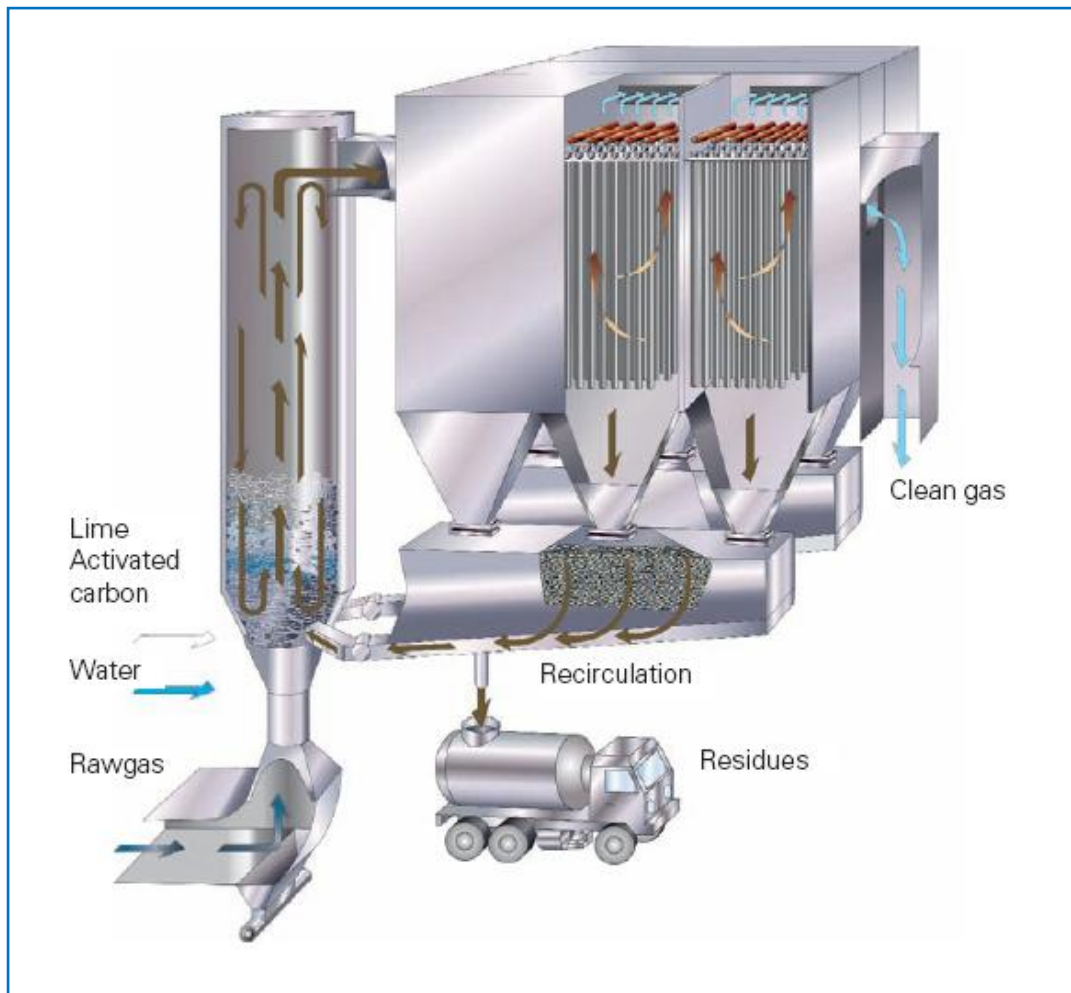
There are several other fairly new APC systems currently being used in Europe. Recently some of the European technologies have been proposed in US. An overview of two such technologies is provided below.

¹¹² European Commission. 2006. Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration

¹¹³ European Commission. 2006. Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration

The Turbosorp solution is promoted by Von Roll Inova. The Turbosorp® process employs a turboreactor with fluidized lime activated carbon and a downstream bag filter. Briefly, the Turbosorp® process works this way: Downstream of the combustion section and steam generator, flue gases are channelled directly into the turbosorber without pre-treatment. Reagents for separation (hydrated lime or calcined lime and activated carbon) are metered into the stream here and water is injected at the same time. The temperature drops below 160°C as a result, improving separation while activating the lime. Pollutants react with the additives in the turbosorber forming products that can be trapped by the downstream fabric filter.^[114] Figure 4-19 provides a schematic overview of the Turbosorp process.

Figure 4-19: Schematic Diagram of the Turbosorp® Turboreactor



Source: Von Roll Inova. 2007. Accessed March 15, 2010 from http://www.aee-vonrollinova.ch/aee_vonroll_inova/products_services/abgasreinigung/turbosorp_r

¹¹⁴ Von Roll Inova. Turbosorp Flue Gas Purification

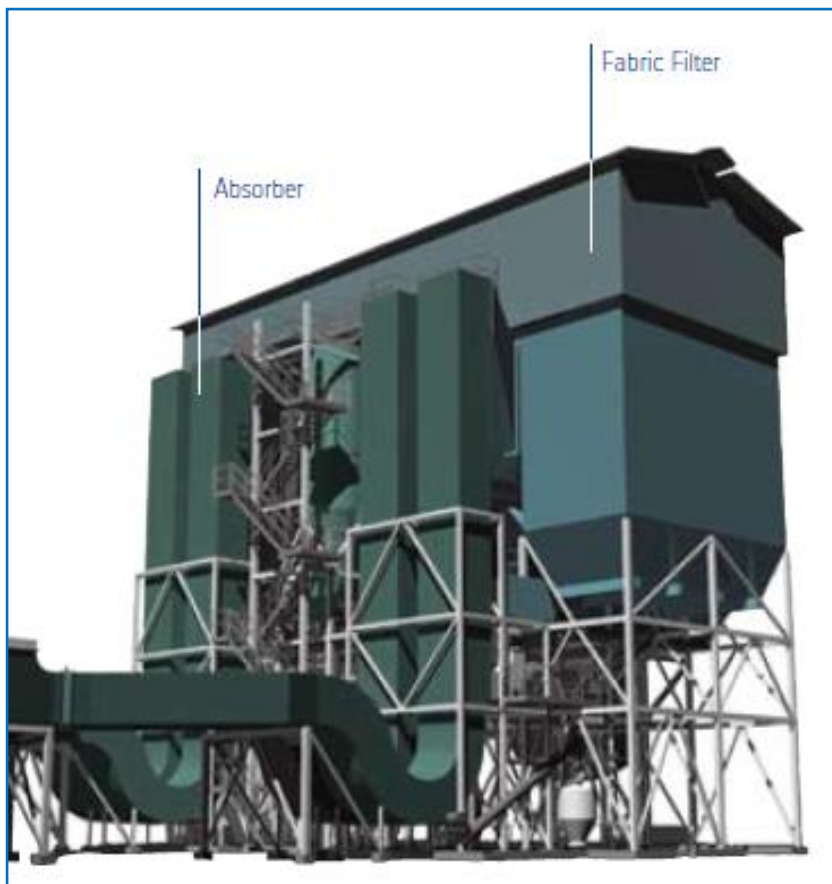
Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 4: Air Emissions Controls

The NID™ system is a Dry Flue Gas Desulphurization (DFGD) process that is based on the reaction between SO_2 and $\text{Ca}(\text{OH})_2$ in humid conditions. The humidified mixture of hydrated lime and reaction product is injected into the NID system absorber and cools the inlet flue gas by evaporation. The cooled flue gas then flows to the dust collector, preferably a Fabric Filter (FF) or an Electrostatic Precipitator (ESP), where the particles in the flue gas are removed and recycled back through the NID FGD system. In addition to desulphurization, the cooled, humid flue gas combined with a fabric filter provide excellent filtration and reaction conditions, resulting in very low particulate emissions and additional gas absorption (SO_2 , HCl , SO_3 , HF , Hg) in the dust cake.

Figure 4-20 presents a schematic overview of the NID System.

Figure 4-20: Schematic Diagram of the NID System



Source: NID™ Flue Gas Desulphurization System for the Power Industry. Alstom. Brochure

4.2.3 APC for Gasification Facilities

The requirement for an APC system for a gasification facility and the type of system it would use, depends primarily on whether or not the syngas being produced is being utilized onsite for energy generation (in which case some type of APC system would be required) or if the syngas is exported

for use off-site.^[115] If the syngas is exported offsite and used for an alternative purpose (i.e., production of hydrogen or methanol) there may be no emissions to air associated with the facility's operation.

The APC system associated with the Nippon Steel "Direct Melting System" and the APC system associated with the Thermoselect technology are discussed below as both are representative of facilities where the syngas is used on-site.

In the Nippon Steel "Direct Melting System", the syngas produced by the melting furnace is combusted immediately within the facility for energy generation. From limited but various sources, Stantec determined that the typical APC train used at these facilities is as follows. After the combustion chamber, the gas is cooled in a conditioning tower (wet spray type). The cooled gas is then passed through a bag filter (to remove particulate matter) and finally, NO_x is reduced via Selective Catalytic Reduction before the flue gas is released via a stack into the atmosphere. At one of their demonstration plants, Nippon Steel utilized an electrostatic precipitator rather than a bag filter. As can be observed, the APC system utilized by Nippon Steel is very similar to that used by mass burn facilities, although some common treatment steps are not present (i.e., activated carbon injection).^{[116],[117]} Based upon the limited data available, it appears that the Nippon Steel technology is capable of meeting European emissions standards.^[118]

Whether or not a gasification facility utilizing Thermoselect technology requires an APC system depends on how the syngas produced by the facility is to be used. A Thermoselect facility is capable of utilizing the syngas onsite to produce energy (via gas engines for electrical power generation or via boilers for heat or power generation) or export offsite to be used to produce energy or as a reagent in the production of various useful products such as methanol or ammonia. If the syngas is to be utilized onsite for energy generation, some type of APC system would be required.

At Thermoselect facilities, high efficiency gas engines are often used on site to produce electricity by combusting the syngas. In this case, the exhaust gas from the engine would be treated by SCR to reduce NO_x emissions and a catalytic converter would be used to reduce CO emissions (convert it to CO₂). Alternatively, the syngas could be used onsite to produce energy via a steam boiler in which case flue gas produced during the process would be treated prior to being released into the atmosphere. NO_x would generally be reduced via SNCR and a dry adsorption unit could be added to the facility to primarily reduce SO₂ and mercury emissions (sodium bicarbonate injection followed by fabric filter).

One way in which the Thermoselect technology assists in reducing the potential emissions to air associated with the combustion of the syngas it produces is via thorough syngas cleaning. Other gasification technologies also often utilize some form of syngas cleaning. Besides the main

¹¹⁵ If the syngas is exported and combusted offsite, the emissions to air associated with the combustion would truly be associated with the gasification facility itself

¹¹⁶ Nippon Steel Technical Report No. 70. July 1996. Research and Development of Direct Melting Process for Municipal Solid Waste.

¹¹⁷ Nippon Steel Technical Report No. 92. July 2005. Development of High-performance Direct Melting Process for Municipal Solid Waste.

¹¹⁸ University of California, Riverside. 2009. Evaluation of Emissions from Thermal Conversion Technologies Processing Municipal Solid Waste and Biomass.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 4: Air Emissions Controls

components of syngas (CO , CO_2 , H_2 , and H_2O), raw syngas also contains HCl , HF , H_2S , dust and metal compounds. The Thermoselect technology cleans syngas in several steps as follows:

- The hot syngas from the high temperature reactor is quenched rapidly preventing the de novo synthesis of dioxins/furans. The quench consists of a graphite cylinder with spraying nozzles.
- The syngas is then “pre-cleaned” by acidic scrubbing. HCl and HF are dissolved in the quench. This lowers the pH value of the quench to approximately a pH of 2 which assists in dissolving heavy metals as chlorides and/or fluorides and also binds trace amounts of ammonia as ammonia chloride.
- Following acidic scrubbing, dust is removed from the syngas. Dust is removed via a de-dusting scrubber (a water jet pump device) which removes dust and carbon particles from the syngas.
- After dust removal, the syngas undergoes desulphurization. This takes place through the adsorption of H_2S and the partial oxidation to elementary sulphur. Iron chelate is sprayed into the syngas flow causing the reaction.
- Fine dust is then removed from the syngas by a wet electrostatic precipitator if the downstream syngas utilization requires very low levels of dust.
- Finally, the syngas is reheated if a wet electrostatic precipitator is used. By reheating, the temperature of the syngas is raised slightly to avoid water condensation in downstream equipment.

As the list illustrates, the syngas cleaning process utilized by Thermoselect is quite thorough and greatly reduces the contaminants present in the syngas, thereby preventing the potential release of these substances into the air if the syngas is combusted. It should be noted that the Thermoselect process does not produce any wastewater. The water condensed during the different phases of the gas treatment is fed into the process water treatment. The process water undergoes a multiple stage treatment and is then reused for cooling purposes.^[119]

4.3 BACT for APC Systems

In both the Netherlands and Austria, for large waste incineration plants, wet flue gas treatment is considered as BACT. These two countries are considered leaders in the use of WTE and have some of the lowest emissions limits in the world, and information regarding the consideration of BACT in these jurisdictions was considered in the development of the European Commission BREF document on BAT for waste incineration.

The EU waste incineration BREF does not suggest the best method for air pollution control as the decision depends on a number of different factors depending on the particular circumstances

¹¹⁹ Thermoselect. 2005. Thermoselect Plant and Process Description

surrounding a facility. The selection of an APC system should be based on the optimal reduction of air emissions, but should also consider other aspects such as ^[120] ^[121]:

- Type of waste, its composition and variation
- Type of combustion process, and its size
- Flue gas flow and temperature
- Flue gas content and fluctuations in flue gas composition
- Land and space availability
- Availability and cost of outlets for residues accumulated/recovered
- Availability and cost of water and other reagents
- Energy supply possibilities
- Availability of subsidiaries for exported energy
- Tolerable disposal charge for the incoming waste
- Reduction of emissions by primary methods (operational controls)
- Generation of noise
- Minimization of effluent discharge
- The additional overall system compatibility issues that arise when retrofitting existing installations
- Consumption of chemicals and energy
- Maximum energy recovery.

Those factors aside, the waste incineration BREF states that an APC system should be selected that can provide for the emissions levels listed in the following table (Table 4-3) for releases to air.

The BREF also provides a comparative matrix to use when selecting between wet, semi-dry and dry APC systems. Although the comparison is not exhaustive, it does provide a helpful overview of the advantages and disadvantages associated with each of the systems. Table 4-4 presents the comparative matrix as given in the BREF document.

In order to ensure that a WTE facility will meet current stringent emissions limits, vendors of WTE technology are often willing to guarantee that their facility will meet certain emission figures lower than the approved limit criteria. Normally, the contract between the client wishing to have the facility and the vendor building the facility will explicitly state the concentration range for each pollutant that would be guaranteed by the vendor. Further, vendors normally specify the raw gas values that they will assume when designing their air pollution control system and would guarantee the amount of substances that their air pollution control system will consume during treatment (i.e., ammonia, lime etc.).

¹²⁰ European Commission. 2006. Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration

¹²¹ Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 4: Air Emissions Controls

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Table 4-3: EU BREF: Operational ELV Ranges Associated with the Use of BAT

Substance(s) (in mg/Nm ³ or as Stated)	Non-Continuous Samples	½ Hour Average	24 Hour Average	Comments
Total dust		1 – 20	1 – 5	In general the use of fabric filters gives the lower levels within these emission ranges. Effective maintenance of dust control systems is very important. Energy use can increase as lower emission averages are sought. Controlling dust levels generally reduces metal emissions.
Hydrogen chloride (HCl)		1 – 50	1 – 8	Waste control, blending and mixing can reduce fluctuations in raw gas concentrations that can lead to elevated short-term emissions. Wet FGT systems generally have the highest absorption capacity and deliver the lowest emission levels for these substances, but are generally more expensive.
Hydrogen fluoride (HF)		<2	<1	
Sulphur dioxide (SO ₂)		1 – 150	1 – 40	
Nitrogen monoxide (NO) and nitrogen dioxide (NO ₂), expressed as NO ₂ for installations using SCR		40 – 300	40 – 100	Waste and combustion control techniques coupled with SCR generally result in operation within these emission ranges. The use of SCR imposes an additional energy demand and costs. In general at larger installations the use of SCR results in less significant additional cost per tonne of waste treated. High N waste may result in increased raw gas NO _x concentrations.
Nitrogen monoxide (NO) and nitrogen dioxide (NO ₂) expressed as NO ₂ for installations not using SCR		30 – 350	120 – 180	Waste and combustion control techniques with SNCR generally result in operation within these emission ranges. 24 hour averages below this range generally require SCR although levels below 70mg/Nm ³ have been achieved using SNCR e.g., where raw NO _x is low and/or at high reagent dose rates) Where high SNCR reagent dosing rates are used, the resulting NH ₃ slip can be controlled using wet FGT with appropriate measures to deal with the resultant ammoniacal wastewater. High N waste may result in increased raw gas NO _x concentrations.
Total Organic Carbon		1 – 20	1 – 10	Techniques that improve combustion conditions reduce emissions of these substances. Emission concentrations are generally not influenced greatly by FGT. CO levels may be higher during start-up and shut down, and with new boilers that have not yet established their normal operational fouling level.
Carbon monoxide (CO)		5 – 100	5 – 30	
Mercury and its compounds (as Hg)	<0.05	0.001 – 0.03	0.001 – 0.02	Adsorption using carbon based reagents is generally required to achieve these emission levels with many wastes – as metallic Hg is more difficult to control than ionic Hg. The precise abatement performance and technique required will depend on the levels and distribution of Hg in the waste. Some waste streams have very highly variable Hg concentrations. Continuous monitoring of Hg is not required by Directive 2000/76/EC but has been carried out in some MSs.
Total cadmium and thallium (and their compounds)	0.005 – 0.05			See comments for Hg. The lower volatility of these metals than Hg means that dust and other metal control methods are more effective at controlling these substances than Hg.
Σ Other metals	0.005 – 0.5			Techniques that control dust levels generally also control these metals.
Dioxins and furans (ng TEQ/Nm ³)	0.01 – 0.1			Combustion techniques destroy PCDD/F in the waste. Specific design and temperature controls reduce de-novo synthesis. In addition to such measures, abatement techniques using carbon based absorbents reduce final emissions to within this emission range. Increased dosing rates for carbon absorbent may give emissions to air as low as 0.001 but result in increased consumption and residues.
Ammonia (NH ₃)	<10	1 – 10	<10	Effective control of NO _x abatement systems, including reagent dosing contributes to reducing NH ₃ emissions. Wet scrubbers absorb NH ₃ and transfer it to the wastewater stream.
Benz(a)pyrene	For these substances there was insufficient data to draw a firm BAT conclusion on emission levels. However, the data indicates that their emission levels are generally low. PCBs, PAHs and benz(a)pyrene can be controlled using the techniques applied for PCDD/F. N ₂ O levels are determined by combustion technique and optimisation, and SNCR optimisation where urea is used.			Techniques that control PCDD/F also control Benz(a)pyrene, PCBs and PAHs
PCBs				
PAHs				
Nitrous oxide (N ₂ O)				Effective oxidative combustion and control of NO _x abatement systems contribute to reducing N ₂ O emissions. The higher levels may be seen with fluidized beds operated at lower temperatures e.g., below ~900°C

- NOTES:**
- The ranges given in this table are the levels of operational performance that may generally be expected as a result of the application of BAT – they are not legally binding emission limit values (ELVs)
 - Σother metals = sum of Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V and their compounds expressed as the metals
 - Non-continuous measurements are averaged over a sampling period of between 30 minutes and 8 hours. Sampling periods are generally in the order of 4 – 8 hours for such measurements.
 - Data is standardized at 11 % Oxygen, dry gas, 273K and 101.3 kPa
 - When comparing performance against these ranges, in all cases the following should be taken into account: the confidence value associated with determinations carried out; that the relative error of such determinations increases as measured concentrations decrease towards lower detection levels
 - The operational data supporting the above-mentioned BAT ranges were obtained according to the currently accepted codes of good monitoring practice requiring measurement equipment with instrumental scales of 0 – 3 times the WID ELV. For parameters with an emission profile of a very low baseline combined with short period peak emissions, specific attention has to be paid to the instrumental scale. For example changing the instrumental scale for the measurement of CO from 3-times the WID ELV to a 10-times higher value, has been reported in some cases, to increase the reported values of the measurement by a factor of 2 – 3. This should be taken into account when interpreting this table.
 - One MS reported that technical difficulties have been experienced in some cases when retrofitting SNCR abatement systems to existing small MSW incineration installations, and that the cost effectiveness (i.e., NO_x reduction per unit cost) of NO_x abatement (e.g., SNCR) is lower at small MSWIs (i.e., those MSWIs of capacity <6 tonnes of waste/hour).

SPLIT VIEWS:

1. BAT 35: Based upon their knowledge of the performance of existing installations a few Member States and the Environmental NGO expressed the split view that the 24 hour NH₃ emission range associated with the use of BAT should be <5 mg/Nm³ (in the place of <10 mg/ Nm³)
2. BAT 35: One Member State and the Environmental NGO expressed split views regarding the BAT ranges). These split views were based upon their knowledge of the performance of a number of existing installations, and their interpretation of data provided by the TWG and also of that included in the BREF document. The final outcome of the TWG meeting was the ranges shown in the table, but with the following split views recorded: total dust 1/2hr average 1 – 10 mg/Nm³; NO_x (as NO₂) using SCR 1/2hr average 30 – 200 and 24hr average 30 – 100 mg/Nm³; Hg and its compounds (as Hg) non-continuous 0.001 – 0.03 mg/Nm³; Total Cd + Tl non-continuous 0.005 – 0.03mg/Nm³; Dioxins and furans non-continuous 0.01 – 0.05 ng TEQ/Nm³. Based on the same rationale, the Environmental NGO also registered the following split views: HF 1/2hr average <1 mg/Nm³; SO₂ 1/2hr average 1 – 50 mg/Nm³ and 24hr average 1 – 25 mg/Nm³

Table 4-4: Example of Some IPPC Relevant Criteria for Selection of APC Systems

Criteria	Wet FGT (W)	Semi-wet FGT (SW)	Dry Lime FGT (DL)	Dry Sodium Bicarbonate FGT (DS)	Comments
Air emissions performance	+	0	–	0	In respect of HCl, HF, NH ₃ and SO ₂ wet systems generally give the lowest emission levels to air. Each of the systems is usually combined with additional dust and PCDD/F control equipment. DL systems may reach similar emission levels as DS and SW but only with increased reagent dosing rates and associated increased residue production.
Residue production	+	0	–	0	Residue production per tonne waste is generally higher with DL systems and lower with W systems with greater concentration of pollutants in residues from W systems. Material recovery from residues is possible with W systems following treatment of scrubber effluent, and with DS systems.
Water consumption	–	0	+	+	Water consumption is generally higher with W systems. Dry systems use little or no water.
Effluent production	–	+	+	+	The effluents produced (if not evaporated) by W systems require treatment and usually discharge – where a suitable receptor for the salty treated effluent can be found (e.g., marine environments) the discharge itself may not be a significant disadvantage. Ammonia removal from effluent may be complex.
Energy consumption	–	0	0	0	Energy consumption is higher with W systems due to pump demand – and is further increased where (as is common) combined with other FGT components e.g., for dust removal.
Reagent consumption	+	0	–	0	Generally lowest reagent consumption with W systems. Generally highest reagent consumption with DL – but may be reduced with reagent re-circulation. SW, and DL and DS systems can benefit from use of raw gas acid monitoring.
Ability to cope with inlet variations of pollutant	+	0	–	0	W systems are most capable of dealing with wide ranging and fast changing inlet concentrations of HCl, HF and SO ₂ . DL systems generally offer less flexibility – although this may be improved with the use of raw gas acid monitoring.
Plume visibility	–	0	+	+	Plume visibility is generally higher with wet systems (unless special measures used). Dry systems generally have the lowest plume visibility.
Process complexity	– (highest)	0 (medium)	+	+	Wet systems themselves are quite simple but other process components are required to provide an all round FGT system, including a wastewater treatment plant etc.
Costs –capital	Generally higher	Medium	Generally lower	Generally lower	Additional cost for wet system arises from the additional costs for complementary FGT and auxiliary components – most significant at smaller plants.
Costs – operational	Medium	Generally lower	Medium	Generally lower	There is an additional operational cost of ETP for W systems – most significant at smaller plants. Higher residue disposal costs where more residues are produced, and more reagent consumed. W systems generally produce lowest amounts of reagents and therefore may have lower reagent disposal costs. Op. costs include consumables, disposal and maintenance costs. Op. costs depend very much on local prices for consumables and residue disposal.

NOTES:

- + means that the use of the technique generally offers an advantage in respect of the assessment criteria considered
- 0 means that the use of the technique generally offers no significant advantage or disadvantage in respect of the assessment criteria considered
- means that the use of the technique generally offers a disadvantage in respect of the assessment criteria considered

5 EXPECTED EMISSION RATES FROM COMBUSTION AND CONTROL SYSTEMS

WTE facilities must be well operated and well maintained to ensure that emissions resulting from their operation are as low as possible. Good combustion practices (i.e., operational controls) can reduce emissions by ensuring that the temperature in the combustion chamber and the retention time for the waste in the combustion chamber are kept at optimal levels. The emissions that are produced during combustion are then reduced further via APC equipment.

5.1 Typical Emissions from Mass Burn Facilities

Table 5-1 illustrates the typical concentration of pollutants in untreated flue gas from a modern conventional mass burn incinerator that treats 15 tonnes of waste per hour for 8,000 hours per year (120,000 tonnes per year). The table also includes the European Union emissions requirements (for comparison purposes) and the typical flue gas quality from a 120,000 tonne per year facility utilizing a semi-dry, wet, or semi-wet APC system.^[122]

As presented in this table and as discussed further within this section of the report, modern WTE facilities with modern APC systems in a variety of configurations are capable of high removal efficiencies for various parameters and can typically achieve emissions that are well within regulated limits. It should be noted that this table presents typical average values for new APC systems, in comparison to the EU emissions requirements. Information presented in Section 5.2, regarding the range of emissions performance for existing WTE plants, includes older facilities that may or may not have recent APC upgrades and thus provide an overview of the range of emissions associated with existing facilities. Care should also be taken in comparing the typical daily average values as presented in Table 5-1 with those that represent average data from either CEM's or Stack Tests (particularly in regards to the averaging periods) as they may not be directly comparable.

Table 5-1: Comparison of Emissions in Raw Flue Gas, EU Emissions Requirements, and Emissions Expected from Semi-Dry, Wet and Semi-Wet APC Systems

Component	Unit	Flue Gas Quality (typical, daily average values)					% Range in Reduction
		Raw Flue Gas	EU Emissions Requirements	Semi-Dry System	Wet System	Semi-Wet System	
Total Particulate Matter	mg/Rm ³	2,000 – 4,500	9.2	3	0 – 2	3	99.90 to 99.95 %
SO ₂	mg/Rm ³	180 – 550	46	<30	1 – 10	15	83.3 to 98.18%
NO _x (with SNCR)	mg/Rm ³	200 – 450	183	<120	<120	<120	40 to 73.3%
HCl	mg/Rm ³	450 – 2,000	9.2	<7	1	2	98.4 to 99.95%
HF	mg/Rm ³	5 – 10	0.92	0.01	0.05	0.05	99.0 to 99.90%
Hg	mg/Rm ³	0.1 – 1	0.046	0.01	0.002	0.002	90 to 99.8%

¹²² Ramboll. 2007. The Regions of Durham and York EfW Facility: Comparison of Flue Gas Treatment Systems

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 5: Expected Emission Rates from Combustion and Control Systems

Component	Unit	Flue Gas Quality (typical, daily average values)					% Range in Reduction
		Raw Flue Gas	EU Emissions Requirements	Semi-Dry System	Wet System	Semi-Wet System	
Cd	mg/Rm ³	1.09 – 2.0	N.A.	0.01	0.002	0.002	99.1 to 99.5%
Cd+Tl	mg/Rm ³	1.0 – 2.0	0.046	0.015	0.005	0.01	98.5 to 99.75%
Pb	mg/Rm ³	25 – 35	N.A.	0.005	0.005	0.005	99.98%
Sum of As, Ni, Co, Pb, Cr, Cu, V, Mn, Sb	mg/Rm ³	5 – 50	0.46	0.05	0.04	0.04	99.0 to 99.92%
Dioxins/Furans I-TEQ	ng/Rm ³	0.009 – 14	0.092	0.08	0.05	0.06	99.6%

NOTE:

Rm³ refers to 25°C

11% O₂, and dry fluegas

NA = Not applicable

5.2 Comparison of Emission Rates from Existing Facilities

The actual air emissions performance of several operating WTE facilities has been reviewed to provide a broad understanding of the emissions from current operating facilities.

Table 5-2 below summarizes the reported emissions from various existing and proposed WTE facilities globally. The emission components are only those actually reported for these facilities; not all facilities are required to report the same components. In regards to the reported values, in many cases the emissions reported are daily averages obtained from CEMs and/or average data reported from stack tests.

Examination of the reported emissions data indicates that in general:

- Modern WTE facilities in North American and EU jurisdictions emit many parameters within the same order of magnitude.
- The range of reported emissions values widens as older facilities are included in the reported range of values.
- The majority of North American and EU jurisdictions require monitoring and reporting of similar emissions, although there are some distinct differences in regards to the monitoring and reporting of trace metals and trace organic parameters.

Table 5-2: Comparison of Emissions from Various Existing WTE Facilities

Component	Unit	Metro Vancouver WTE Facility (2007) ^[1]	Modern Italian Waste Incinerator ^[2]	Emissions from retrofitted UK plant (2001) ^[3]	Sheffield Energy Recovery Facility (UK) (March 2010) ^[4]	SELCHP (UK) (December 2009) ^[5]	Range from European MSW Incinerators (2006) ^[6]			Average Values from 87 US WTE Facilities ^[7]	Average of Three High Performing US Facilities ^[7]	Average of 10 Finalists in WTERT 2006 Award ^[7]	SEMASS (US) (July 2006) ^[8]	Wels (Austria) (2000) ^[11]	Spittelau (Austria) (2000) ^[11]	Flotzersteig (Austria) (2000) ^[9]	Average Values from Dutch Incinerators (2002) ^[10]
				Daily Average	Daily Average	Daily Average	Annual Average	Daily Average	Half Hour Average		Daily Average	Daily Average		Half Hour Average	Half Hour Average	Half Hour Average	Daily Average
Total Particulate Matter	mg/m ³	3.8	1.9	0.84	0.75	3.63	0.093–3.73	0.093–9.32	<0.047–13.98	2.8	1.0	2.9	1.7	<0.47	0.75	1.96	0.47–2.8
CO	mg/m ³	23	9.3	4.7	1.86	5.59	1.86–42	0.93–93	0.93–140		11.5	22.4	37.7	18.6	24.5	14.2	4.66–47
SO ₂	mg/m ³	85	7.5		8.39	1.86	0.19–19	0.47–47	0.093–233	11.2	5.3	2.8	71.7	<1.86	1.96	9.69	1.86–28
NO _x	mg/m ³	265	130.4	255.3	85.53	144.42	18.6–168	28–186	18.6–419	227.7	46.3	104	204	50.3	21.4	28.4	37.2–65
HCl	mg/m ³	23.6	6.5	18.6	5.40	4.85	0.093–5.6	0.093–9.3	0.093–75	10.6	1.5	7.9	8.4	<0.093	0.75	0.093	0.47–4.7
HF	mg/m ³	0.1	0.65	<0.093			0.009–0.09	0.09–0.093	<0.019–0.9					<0.047	<0.019	0.13	0.093–0.47
VOCs	mg/m ³		3.07														
TOC	mg/m ³				0.93	0.19	0.093–4.7	0.093–9.3	0.093–23		0.65	0.95			0.47		0–9.32
Methane	mg/m ³	4.3															
Hg	mg/m ³	0.002	0.009				0.00019–0.047	0.0047–0.047	0.0013–0.034	0.007	0.0028	0.0093	0.0009	<0.0019	0.065	0.0335	0.0047–0.019
Cd	mg/m ³	0.0006	0.009	<0.00093				0.0003–0.003		0.0007			0.0001	<0.0019	0.00093	0.00186	
Cd,Tl	mg/m ³						0.0002–0.028										0.0009–0.0093
Pb	mg/m ³	0.0059	0.093					<0.002–0.041		0.014			0.0127	<0.0019	0.0112	0.041	
Sum of As, Ni, Co, Pb, Cr, Cu, V, Mn, Sb	mg/m ³			<0.932			0.0002–0.047										
PAH	µg/m ³	0.13					<9.324										
PCB	µg/m ³	0					<4.66										
Dioxins/Furans I-TEQ	ng/m ³	0.002	0.047	0.0056			0.00019–0.075			0.04	0.0019	0.0186	0.024	0.0028	0.0186	0.0168	0.009–0.047

NOTES:

Reference conditions: 101.3 kPa, 20°C, dry gas, 11% O₂

¹ AECOM Canada Ltd. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

² M. Guigliano, *et al.* 2008. Energy Recovery from Municipal Waste: A Case Study for a middle-sized Italian District. In Waste Management 28 (2008) 39 – 50 (representative of modern WTE plants equipped with a dry flue gas cleaning system (dry scrubbing + activated carbon) followed by a fabric filter. Nitrogen oxides are controlled by selective non-catalytic reduction activated by urea.)

³ Porteous. 2001. Energy from waste incineration - a state of the art emissions review with an emphasis on public acceptability.

⁴ Sheffield Energy Recovery Website (<http://www.veoliaenvironmentalservices.co.uk/sheffield/pages/emissions.asp>) (All based on continuous measurements).

⁵ SELCHP Website (<http://www.selchp.com/emissions.asp?year=2009&emissionId=48>) (All based on continuous measurements). APC system is comprised of SNCR, semi-dry lime and activated carbon injection.

⁶ European Commission. 2006. Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration. (All based on continuous measurements except for heavy metals and dioxins/furans which are based on sampling periods generally in the order of 4 – 8 hours).

⁷ C.S. Psomopoulos, *et al.* 2009 Waste-to-energy: A review of the status and benefits in USA. (All based on continuous measurements except for heavy metals and dioxins/furans which are based on spot samples).

⁸ SEMASS Boiler NO. 3 Test Results.

⁹ European Commission. 2006. Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration. APC system includes ESP, three wet scrubbers, and SCR. TPM, HCl, SO₂, TOC, CO, NO_x are based on CEMS, rest are based on discontinuous measurements.

¹⁰ Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT for the Incineration of Waste. (All based on continuous measurements except for heavy metals and dioxins/furans which are based on spot samples). Almost all Dutch incinerators employ wet scrubbers and SCR.

¹¹ European Commission. 2006. Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration. APC system includes ESP, two wet scrubbers, and activated coke filter, and SCR, TPM, HCl, HF, SO₂, TOC, CO, NO_x are based on CEMS, rest are based on discontinuous measurements.

¹² European Commission. 2006. Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration. APC system includes SNCR, two fabric filters and wet scrubbing. TPM, HCl, SO₂, TOC, CO, NO_x are based on CEMS, rest are based on discontinuous periodic measurements.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices
Final Report
Section 5: Expected Emission Rates from Combustion and Control Systems

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It should be noted that the basis on which emission rates are calculated vary by jurisdiction. Emissions from combustion facilities must be adjusted, or 'corrected', to pre-determined standard conditions. Most emissions are reported on a mass per volume basis, such as milligrams per standard or reference cubic metre (mg/Rm³). The correction to standard conditions is necessary because, as a gas, the volumetric rate of discharge will vary as a result of temperature and pressure (gauge and absolute). The rate also varies with the composition of the gaseous constituents, such as percent O₂ and CO₂. BC Standard Conditions are 20°C, 101.325 kPa, dry gas (0% moisture) and include site specific standard conditions for %O₂ or %CO₂.

5.3 Air Emissions Quality Trends

Air emissions from modern state-of-the-art WTE facilities are greatly reduced in comparison to older facilities that have less stringent operational controls and less effective air pollution equipment and monitoring systems. WTE tends to be highly regulated in consideration of the potential effects of emissions on human health and the environment, and public perception. For this reason, developed countries have very strict emissions standards. Contemporary air pollution control technologies have been developed to stay well within these limits.^[123]

In the United States, there are currently 89 operating WTE facilities that treat MSW. The emissions from WTE facilities have decreased substantially over the past number of decades due to improvements made to waste combustion technologies. A memorandum released by the United States Environmental Protection Agency in 2007 presented the overall emissions reductions achieved by large and small municipal waste combustion (MWC) units which were retrofitted with Maximum Achievable Control Technology from 2000 to 2005. The table presents the emissions from these large and small municipal waste combustion (MWC) Units in 1990 (prior to retrofits) and in 2005 (after retrofits). As the table illustrates, the reduction of emissions was quite significant.^[124]

Table 5-3: Emissions from Large and Small MWC Units at MACT Compliance (US EPA)

Pollutant	1990 Emissions (tpy)	2005 Emissions (tpy)	Percent Reduction
Dioxins/Furans, TEQ basis	4,400	15	99+%
Mercury	57	2.3	96%
Cadmium	9.6	0.4	96%
Lead	170	5.5	97%
Particulate Matter	18,600	780	96%
HCl	57,400	3,200	94%
SO ₂	38,300	4,600	88%
NO _x	64,900	49,500	24%

¹²³ European Commission. 2006. Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration

¹²⁴ United States EPA. 2007. Memorandum: Emissions from Large and Small MWC Units at MACT Compliance

5.4 Factors Affecting Emission Rates

A number of factors affect the emissions rates from the thermal treatment of MSW. Generally, the following factors are the main contributors to emission performance:

- Waste composition and content (depends on jurisdiction and diversion practices in place)
- Thermal treatment technology (the design and operation of the thermal treatment facility)
- Design and operation of the APC equipment.

The following subsections will discuss each of the factors that affect emissions in greater detail.

5.4.1 Waste Composition and Content

Several of the substances of concern that are emitted to air from WTE facilities originate from the MSW being treated. For example, the release of heavy metals such as mercury and cadmium as well as acidic gases such as SO₂ and HCl from WTE facilities is driven largely by the presence of these substances in the post-diversion waste stream.

As an illustration, if the post-diversion waste stream contains a lot of mercury laden waste (compact fluorescent light bulbs, mercury thermometers), more mercury is likely to be released into the atmosphere, even after the flue gas is treated with state-of-the-art APC equipment. Therefore, it is desirable in jurisdictions which utilize thermal treatment to try and minimize contaminants present in the residual waste stream. The composition of MSW depends on the types and quantities of materials being placed in the garbage stream by residents. This depends on the types of diversion programs available in a given jurisdiction, the public's participation in these programs, as well as the types of materials being used and disposed of in a given jurisdiction.

BC has been particularly active at removing these contaminants from the waste stream – further information is available on the web at: <http://rcbc.bc.ca/education/retailer-take-back>.

The following table illustrates how the removal of various materials from the residual waste stream will affect the thermal treatment of the remaining waste stream.^[125]

Table 5-4: Impact of Material Removal and Pre-treatment on Residual Waste

Materials Removed	Impact on the Remaining Waste
Electronics	<ul style="list-style-type: none">▪ Increase in calorific value▪ Decrease in hazardous metal loading, may reduce chlorine loads
Glass and Metals	<ul style="list-style-type: none">▪ Increase in calorific value▪ Decrease in quantity of recoverable metals in slag (or bottom ash)
Paper, Cardboard and Plastic	<ul style="list-style-type: none">▪ Decrease in calorific value▪ Possible reduction in chlorine loads if PVC plastic is common

¹²⁵ European Commission. 2006. Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration

Materials Removed	Impact on the Remaining Waste
Organic Wastes (food and garden materials)	<ul style="list-style-type: none"> Reduction in the moisture loads (particularly during peak loads) Increase in calorific value
Bulky Wastes	<ul style="list-style-type: none"> Reduced need for removal/shredding of such wastes
Hazardous Wastes	<ul style="list-style-type: none"> Reduction in hazardous metal loading Reduction in some other substances (e.g., Cl, Br)
Construction and Demolition Waste	<ul style="list-style-type: none"> Reduction in sulphur content (gypsum from drywall).

Having a diversion program in place does not necessarily mean that it will capture the targeted materials unless residents participate regularly in the program. For example, if a resident discards compact fluorescent light bulbs but chooses not to participate in his/her community's hazardous waste diversion program, this will lead to increased levels of mercury in the waste stream and thus increase the potential for mercury release during thermal treatment. Most jurisdictions try to increase public participation in their diversion programs through aggressive promotion and education campaigns.

Finally, even if a jurisdiction has a mature waste management system and regular participation by residents in the diversion programs, this does not definitively mean that potential hazardous materials will be removed from the garbage stream. For example, if manufacturers increase the use of non-recyclable PVC plastic within their products, the overall chlorine content of the waste will increase leading to a potential increase in HCl production during the thermal treatment of the waste material. The removal of potentially hazardous materials from the residual waste stream is difficult as policies which govern materials such as packaging and product formulation are usually out of the local jurisdiction's control.

5.4.2 Selection of Thermal Technology

The thermal treatment technology being used to treat MSW also has a significant impact on the emissions released. Differences will be observed from technology to technology and within each technology grouping.

The proper operation of a thermal treatment facility plays a significant role in emissions performance. If appropriate operational controls are maintained over the combustion process (proper temperature and residence time, adequate overfire air) less emissions of organic compounds and products of incomplete combustion will be realized (e.g., dioxins/furans, CO). Additionally, the waste stream can be pretreated to ensure proper homogenization and removal of undesirable materials. The above examples are by no means an exhaustive list of potential operational considerations but are meant for illustrative purposes only.

5.4.3 Design and Operation of APC Equipment

The design and operation of a WTE facility's APC equipment will have a significant impact on the type and rate of emissions arising from its operation. As discussed in previous sections, different types of APC trains (i.e., wet, semi-dry) are capable of reducing emissions to varying levels. Wet

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 5: Expected Emission Rates from Combustion and Control Systems

systems tend to provide more flexibility and are typically able to reduce emissions to a greater degree than dry systems.

In addition to the type of APC system, the operation of a given system will also have a great effect on emissions reduction performance. If a system is well maintained and operated under optimal conditions, the rate of emissions will be reduced. For example, in a fabric filter baghouse, the filter cake should be kept at a particular thickness so as to capture the majority of particulate matter without reducing air flow too significantly.

As another example, SNCR systems are capable of reducing NO_x emissions well below emissions requirements depending on the quantity of reagent (NH₃) added to the flue gas stream. The amount of reagent added depends on the desired emissions levels as well as the costs associated with reagent supply.

6 EMISSIONS FROM USE OF REFUSE DERIVED FUEL

6.1 RDF Overview

The composition of Refuse Derived Fuel (RDF) produced from MSW varies according to the origin of the waste material and the sorting/separation process used to produce the RDF. The following table (Table 6-1) presents an overview of the typical composition of RDF produced through the processing of MSW.^[126]

RDF, which is also often called Solid Recovered Fuel (SRF), is typically produced by processing municipal solid waste through: shredding, selective materials recovery (metals), dehydrating and packaging for transport into bale, brick or pellet form. RDF can be comprised of more homogenous residue streams generated by industry such as off-cuts from production of packages, or inorganic (plastic) residues removed from finished compost. RDF can also be generated through source separation of specific material streams such as separation of clean or contaminated wood waste materials from construction and demolition wastes.

Other waste materials can also be processed into waste derived fuels. Waste tires have been used as a fuel supplement as tire derived fuel (TDF) in cement kilns and pulp mill power boilers.

Table 6-1: Typical Composition of RDF Derived from MSW

Waste Fraction	Flemish Region		Italy	UK
	Resulting from Sorting Process (%)	Resulting from Mechanical/Biological Treatment (%)	%	%
Plastic	31	9	23	11
Paper/Cardboard	13	64 ⁽¹⁾	44	84
Wood	12	25 ⁽²⁾	4.5	5 ⁽⁴⁾
Textiles	14		12	
Others	30		14 ⁽³⁾	
Undesirable material (glass, stone, metal)		2	2.5	
Dry-solid content	66%	85%	–	–

NOTES:

⁽¹⁾ Includes, paper, textile, wood

⁽²⁾ Includes rubber, synthetic material

⁽³⁾ Includes organic degradable waste

⁽⁴⁾ Includes glass, wood, textiles and metals

In all cases, the application of this supplemental fuel in industrial or other applications, involves waste materials that have been processed in some way to make them more suitable for introduction

¹²⁶ European Commission – Directorate General Environment. 2003. Refuse Derived Fuel, Current Practice and Perspectives (B4-3040/2000/306517/MAR/E3) Final Report

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 6: Emissions from Use of Refuse Derived Fuel

into the fuel feed system and to optimize thermal and emissions performance. Unprocessed, raw MSW is not used as a supplemental fuel supply for industrial applications as it would generally not be considered suitable from an operational standpoint given that it is highly heterogeneous.

Beyond the practical advantages of blending the fuel supply, the biogenic portion of RDF may have an environmental and/or monetary value in terms of GHG offsets from fuel substitution if GHG emissions are reduced compared to a business-as-usual scenario and the fuel substitution meets applicable criteria.

Refuse derived fuel (RDF) can be produced from municipal solid waste (MSW) through a number of different processes including the following:

- Separation at source
- Sorting or mechanical separation
- Size reduction (shredding, chipping and milling)
- Separation and screening
- Blending
- Drying and pelletizing
- Packaging
- Storage.

Processing includes removal of any components that could pose quality and environmental concerns. The purpose of the processing of MSW is to generate a fuel source that is relatively homogenous and free of any undesired components.

There are two primary approaches which can produce a high calorific fraction from domestic MSW, which can be used as RDF:

- Mechanical Biological Treatment
- Dry Stabilisation Process.

In a mechanical biological treatment facility (MBT), mixed solid wastes are separated into the following:

- Metals (recovered for recycling)
- Inert materials
- Organic materials (often stabilized using composting processes or anaerobic digestion)
- A residual fraction that has a high-calorific value as it is composed mainly of dry residues of paper, plastics and textiles that can be used as an RDF.

RDF can also be produced through a 'dry stabilization' process, in which residual waste (following removal of the inert portion of the waste and metals) are effectively dried (and stabilized) through a composting process, leaving the residual mass with higher calorific value and suitable for combustion.

The quantity of RDF produced per tonne of processed MSW varies depending on the type of collection, treatment process and quality requirements. The rate of RDF production from MSW can vary between 25 and 85% by weight of waste processed depending on the treatment process used.

The final form and characteristics of RDF produced through processing facilities is usually tailored to the intended industrial application of the material, as the specifications in regards to fuel quality, composition, particle size and density etc. can vary significantly from application to application. The following sections provide discussion on two specific applications of RDF within BC industry, followed by general discussion on how the use of RDF in general should be regulated within the province.

6.2 RDF Use in Wood Fired/Pulp Mill Boilers

6.2.1 General Discussion

Typically, pulp mill boilers are designed to combust relatively clean wood waste in the form of bark, sawdust and small dimension chunks of woody debris, commonly called hog fuel. Contaminants in the hog fuel will vary depending on the location of the mill and source of hog fuel. For example, coastal mills burning wood residuals from timber boomed in salt water will have elevated concentrations of chloride. Timber boomed in a river will have a higher concentration of silt and sand mixed in, potentially forming a nuisance slag in the furnace. There are few other contaminants in the fuel supply for wood fired boilers. Metal, plastic and chlorinated organic compounds are, for the most part, absent from the fuel supply.

Pulp mill boiler APC equipment typically consists of cyclones, baghouses and ESPs, used singly or in combination. Systems to control acid gas or to capture toxic organic compounds are not normally installed on these types of boilers, as these contaminants of concern are not normally produced. Particulate emissions, opacity of the discharge and gaseous components including NO_x, SO_x, CO and unburned hydrocarbons are typically the emissions of concern with wood fired boiler systems. If salt laden wood is burned dioxins and furans are also released (for these situations Ministry permits contain appropriate emission limits). The BC MOE previously commissioned a report on emissions from wood fired combustion equipment in BC which discusses facility and APC design and costs, current performance and achievable emissions limits for various wood fired combustion approaches.^[127]

There is interest in BC to use wood fired boilers for treatment of construction and demolition wastes that have been processed to remove undesirable constituents, such as gypsum, plastic and metals. The option is attractive given the potential to supplement fuel in areas where fibre and fuel supply is constrained. It also eliminates the need for landfilling these wastes while providing the opportunity to convert the waste to energy in the form of electricity, process steam or potentially district heat.

There are a number of constraints to the use of wood fired combustion boilers for treatment of MSW, RDF or construction and demolition debris, including:

¹²⁷ Envirochem, 2008. Emissions from Wood-Fired Combustion Equipment
http://www.env.gov.bc.ca/epd/industrial/pulp_paper_lumber/pdf/emissions_report_08.pdf

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 6: Emissions from Use of Refuse Derived Fuel

- The waste type needs to be of similar type to the design fuel source intended for the boiler. Issues around calorific value, moisture content and the presence of contaminants of concern can be minimized if the fuel supply is limited to predominantly wood. Raw MSW and most types of RDF will not be suitable for this application as a result of elevated plastic and metal in the fuel supply. Unsorted demolition waste is also not likely to be compatible with the combustion and APC systems as a result of contamination by plastic, gypsum, textile wastes and metals.
- The facility has to have the ability to feed the wastes into the boiler in a manner that maintains operational control and performance without adversely affecting emission quality. It would be necessary to shred (hog) woody debris to make it suitable for feeding into the boiler.
- Given that even processed RDF or construction and demolition waste may include contaminants not present in hog fuel from a sawmill, controlling and monitoring emission quality relative to the ELVs in the facility permit and/or other emission criteria or standards is critical. For example, the current emission limit values for total particulate from wood fired power boilers is typically higher than the value for WTE facilities. Particulate ELVs in BC for wood fired boilers in a non-urban setting range between 120 mg/m^3 to 230 mg/m^3 , in contrast to the current WTE facility particulate ELV of 20 mg/m^3 . The current ELVs for wood fired boilers typically do not specify concentrations of trace metals or toxic organic compounds whereas these are important criteria for a WTE facility.
- In many cases it is reasonable to anticipate that it will be uneconomic to retro-fit APC systems to treat the host of other emissions (in addition to particulate for instance) not normally produced by firing wood waste. Therefore, the emission quality has to be essentially unchanged from the design emission produced by the facility when operating solely on wood waste.

The following sub-sections discuss proposed approaches for the application of two RDF streams in wood fired boilers being wood waste and tire-derived fuel, as these are the potential RDF streams in which the most interest has been demonstrated to-date for such applications.

6.2.2 Use of Wood Waste in Pulp Mill/Wood Fired Boilers

Construction and demolition wastes includes discarded materials generally considered to be not water soluble and non-hazardous in nature, including but not limited to steel, glass, brick, concrete, asphalt material, pipe, gypsum wallboard, and wood waste, from the construction or destruction of a structure or from the renovation of a structure. Wood wastes arising from construction include off cuts from structural timbers, timber packaging, scaffolding, wooden hoardings, whereas wood wastes arising from demolition include used structural timbers, e.g., floorboards, joists, beams staircases and doors.

For the purpose of distinguishing between wood waste sources that could be used as alternative fuels for wood fired boilers, the following defines the two broad categories of wood waste based fuels that may be suitable when recovered from the construction and demolition waste stream.

1. “Clean” wood waste means uncontaminated wood or wood products, from which hardware, fittings and attachments, unless they are predominantly wood or cellulose, have been removed (e.g., clean wooden shakes and shingles, lumber, wooden siding, posts, beams or logs from log home construction, fence posts and rails, wooden decking, millwork and cabinetry), and **excludes**:
 - Any engineered or chemically treated wood products, such as products with added glues or those treated for insect or rot control (oriented strand board, plywood, medium density fibre board, wood laminates or wood treated with chromated copper arsenate, ammoniacal copper arsenate, pentachlorophenol or creosote)
 - Upholstered articles
 - Painted or varnished wood articles or wood with physical contaminants, such as plaster, metal, or plastic
 - Any wood articles to which a rigid surface treatment is affixed or adhered.

Clean wood waste also excludes other materials found in the construction and demolition waste stream such as gypsum or drywall, fibreglass, asphalt or fibreglass roofing shingles, metals or plastics.

2. “Contaminated” wood waste is primarily composed of wood or wood products, but may include of engineered wood products, painted or treated wood, gypsum or drywall, fibreglass, asphalt or fibreglass roofing shingles, metals or plastics.

Land clearing waste is not considered as part of the construction and demolition waste stream for the purpose of this discussion. The sources of land clearing waste can range from land clearing by individual property owners on acreages to developers clearing areas for entire subdivisions.

Generally entire trees are removed, including the root systems which contain soil. In many cases this debris is not left to season before it is disposed of, which results in less than optimal fuel because of the high moisture content and the existence of large quantities of soil.

The chemical composition of clean wood waste and its fuel characteristics are essentially the same as the current permitted fuel stream for existing wood fired boilers. Combustion of clean wood waste as defined above, within existing wood waste boilers, can be accommodated by existing facilities within the currently permitted emissions limits and would be regarded as a minor modification to current operations. Fuel testing would be necessary both initially (to support minor permit changes) and during regular operations to ensure that the wood waste fuel accepted for combustion, continues to meet regulated specifications for ‘clean’ wood waste.

Combustion of wood waste contaminated with organic and inorganic wood protection and wood preservation chemicals has been conducted in BC power boilers over the past two decades. This includes wood contaminated with creosote (railway ties and some structural timber), and pentachlorophenol treated wood (utility pole and some structural timber). It should be noted that chlorophenol use as a wood protection (anti-sapstain) chemical was discontinued in the early-1990s and chlorophenols are now only found in limited wood preservation applications. Therefore, the presence of chlorophenols in refuse derived fuel is now considered to be unlikely. In the past, these

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 6: Emissions from Use of Refuse Derived Fuel

waste streams have been included on a limited fuel substitution basis in trial burns. While these tests have generally resulted in acceptable emissions from the facility, other constraints including public concern and waste material handling have prevented adoption of larger programs of fuel substitution with these materials. Other applications of 'contaminated' wood waste have included the use of wood waste contaminated by other construction and demolition materials.

Substitution and supplementing fuel supply with 'contaminated' wood waste should be acceptable under specific conditions and would require amendment of current facility permits as follows:

- Use of 'contaminated' wood waste as fuel would likely be considered a major modification to the operations for a given facility and would require permit amendments to address operational changes and revised ELVs, which for a number of parameters would be consistent with those proposed for WTE facilities.
- Testing of the proposed fuels including mass balance analysis to determine the potential shift in emissions concentrations at various substitution rates would be required. This should be accompanied by fuel trials undertaken to demonstrate the actual shift in emissions concentrations associated with use of the proposed fuels.
- As part of the permit amendments, revised ELVs would be necessary in order to limit the potential for effects from air emissions. Revised ELVs could reflect the following:
 - Revised particulate limits to reflect new performance expectations in accordance with those identified in the Envirochem report "Emissions from Wood-Fired Combustion Equipment" which suggests that achievable particulate emission limits for wood fired boilers are in the order of 35 mg/m³ for facilities ranging in size from 3 to 39 MWh or 20 mg/m³ for facilities of 40 MWh and larger.^[128]
 - Retention of the existing limits for CO and NO_x given that emissions performance for these parameters is based on general facility design and operations.
 - Application of the limits proposed for other parameters (heavy metals, persistent organic pollutants) based on those proposed for municipal solid waste incinerators (Section 9.3).
- Fuel quality testing should be undertaken initially to ensure the proposed source and type of material is suitable for consideration, during fuel testing to demonstrate the potential fate of various parameters in the fuel during the combustion process and on a regular basis during operations to ensure that fuel quality specifications (both regulated and unregulated) are being met. During normal operations, it would be reasonable in the first few years for the facility to test its contaminated wood waste fuel supply at least quarterly through random samples to ensure compliance with permits and to ensure that the fuel suppliers meet the requirements set out by the operator.

¹²⁸ Envirochem, 2008. Emissions from Wood-Fired Combustion Equipment
http://www.env.gov.bc.ca/epd/industrial/pulp_paper_lumber/pdf/emissions_report_08.pdf

- Proponents that intend to use a 'contaminated' wood waste as a portion of their fuel stream, would need to identify the proposed rate of fuel substitution and would have to demonstrate their ability to meet the revised ELV's as discussed above, at the proposed maximum substitution rate.

6.2.3 Use of Tire Derived Fuel in Pulp Mill/Wood Fired Boilers

In North America, the use of supplementary fuels in the pulp industry has generally been limited to TDF. About 26 million tires per year are consumed as fuel in US pulp and paper mill power boilers. These facilities typically use wood waste as the primary fuel supply, but the operators have found that the use of TDF increases the stability of the boiler performance. TDF is used in many plants as a supplement to wood because of its high heat value and low moisture content. TDF produces 100 – 200% more energy than wood on a mass basis, according to the US Environmental Protection Agency. The main problem in using TDF in the pulp industry is the need to use de-wired tires. Pulp mills use TDF instead of whole tires because metal wires clog the feed systems. De-wired TDF can cost up to 50% more than regular TDF.^[129]

Within BC, one coastal paper mill supplements the wood waste fuel supply with TDF in one of its three boilers. The boilers were redesigned in the late 1990s to accommodate the use of TDF, believed to be a necessary addition resulting from shortages in fuel supply and an apparent downward trend in the quality of fuel. TDF was selected as a supplementary fuel partly due to the proximity of a local tire recycling facility.

Potential environmental issues relating to the use of TDF at this facility included the risk of:

- Increase in particulate emissions
- Increase in zinc content of the fly ash
- Increase in sulphur content potentially resulting in acid gas generation
- Increase in other trace toxic organic emissions (such as dioxins and furans) that may affect emissions and ambient air quality.

After receiving approval to allow 2 – 5% TDF, performance monitoring results revealed stabilization of the boiler operation when burning lower quality hog fuel, increased fluidized bed temperature, and approximately 5% increase in hog fuel burn rate. Emission monitoring revealed that there was no impact of TDF addition on the total particulate emissions, SO₂ emissions, and no increase in any of the metals in the stack emissions compared with the baseline measurements. Zinc and iron content in fly ash and bottom ash increased. There was no increase in the trace levels of dioxins and furans in the fly ash from TDF addition to the boiler.^[130]

¹²⁹ United States Environmental Protection Agency (September 2008), *Tire-Derived Fuel*, Retrieved February 23, 2010, from <http://www.epa.gov/osw/conservation/materials/tires/tdf.htm>

¹³⁰ L. Cross and B. Ericksen, *Use of Tire Derived Fuel (TDF) in a Fluidized Bed Hog Fuel Paper Boiler at Pacifica Papers Inc.*, Retrieved February 23, 2010, from http://www.portaec.net/local/tireburning/use_of_tire_derived_fuel.html

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 6: Emissions from Use of Refuse Derived Fuel

Proper equipment or modifications to reduce emission levels are required to burn TDF in these boilers. Several emission control devices and techniques are known, and these have decreased emission levels to within standards. Only a small percentage of industrial boilers have the required combination of system design and fuel type conducive to appropriate TDF substitution and controlling SO_x and particulate emissions is required. SO_x can be controlled by scrubbers present in some systems, especially if the scrubbers operate at a neutral or basic pH. An efficient particulate control device (electrostatic precipitator) is required to prevent increased particulate emissions when burning TDF.^[131] A proper feed system to provide a consistent and well controlled TDF feed rate is recommended. Proper combustion air control on the boiler is required to ensure efficient combustion of the TDF.^[132]

Existing boilers can be modified to meet the requirement for such high temperatures; however these modifications, in addition to TDF processing, can be expensive depending on the model. Until the cost of processing and equipment are lowered the use of TDF will be limited.^[133]

6.3 Use of RDF by Cement Kilns

Cement is a fine grey powder that is mixed with gravel, sand, and water to form concrete, the most widely used construction material in the world. In 2008, the Canadian cement industry produced 14 million tonnes of cement, worth more than \$1.8 billion. Currently, there are 16 operating cement plants in Canada, with three of these located in BC.^[134]

The production of cement consumes a significant amount of raw materials and energy. For example, a dry process cement plant needs roughly 1,600,000 tonnes of raw materials and 150,000 tonnes of fuel (high quality coal) to produce 1,000,000 tonnes of Portland cement clinker per year.^[135] Due to the high consumption of natural resources used in cement production, the cement industry has for many years been investigating the use of alternative raw materials and fuels to help offset the consumption of natural resources without compromising the quality of the cement produced or increasing the environmental impact of cement manufacture.

The European cement industry has been increasingly substituting the use of natural resources for raw materials and fuels with alternative waste-derived materials in order to decrease the environmental impact of their operations. Often these alternative materials are selected industrial by-products and waste streams which have been found to be suitable for cement production due to their physical and chemical properties.

¹³¹ T.A.G. Resource Recovery (November 1997), *Tire Derived Fuel: Environmental Characteristics and Performance*, Retrieved February 23, 2010, from <http://www.p2pays.org/ref/24/23765.pdf>

¹³² L. Cross and B. Ericksen, *Use of Tire Derived Fuel (TDF) in a Fluidized Bed Hog Fuel Paper Boiler at Pacifica Papers Inc.*, Retrieved February 23, 2010, from http://www.portaec.net/local/tireburning/use_of_tire_derived_fuel.html

¹³³ Unknown Author, *Recycling Options*, Retrieved February 23, 2010, from <http://www.p2pays.org/ref/11/10504/html/biblio/htmls2/cgh4.html>

¹³⁴ The Cement Association of Canada. 2010. The Cement Association of Canada – Economic Contribution

¹³⁵ CEMBUREAU. 2004. The Sustainable Use of Alternative Resources in the European Cement Industry

Common alternative waste-derived raw materials used in cement manufacturing in Europe include fly ash, blast furnace slag, silica fume, iron slag, paper sludge, pyrite ash, spent foundry sand, soil containing oil and artificial gypsum (gypsum produced from industrial processes such as acid neutralization). These waste materials are suitable as they are chemically appropriate and provide the constituents required for the production of clinker.^[136]

Alternative waste-derived fuels are also commonly used in cement manufacture. The suitability of an RDF for use in a cement kiln as a fuel is contingent upon the material having the appropriate consistency, heat value and composition as follows:

- The particle size of the fuel is an important factor in determining the suitability of a fuel for use in a cement kiln. Fuels with a particle size of less than 12 mm are acceptable to be introduced directly into the kiln. Fuels with a particle size of less than 50 mm are acceptable to be injected into the precalciner for those facilities that include a precalciner in their design.
- Fuels with a calorific value ranging from 15 to 18 MJ/kg are more suitable to be introduced into the precalciner and fuel with a higher calorific value ranging from 20 to 25 MJ/kg are more suitable to be injected into the kiln.
- The composition of the fuels must be in the appropriate range in regards to moisture content, ash content, sulphur and chlorides as well as trace heavy metals.

In many jurisdictions where the use of alternative fuels has been well established, there are regulations/guidelines in place to regulate their use. The regulatory requirements/guidelines for the maximum levels of contaminants in alternative fuels from some of these jurisdictions are presented in Table 6-2, below. The focus is on regulating contaminants that could contribute to the emissions of chlorinated organic pollutants and heavy metals. It should be noted that generally the mass of chlorine and trace heavy metals within a cement kiln will be dominated by the contribution of these parameters from the raw materials used in cement manufacture. The contribution to the discharge of these contaminants from any fuel source is comparatively small.

Common alternative waste based fuels used in cement manufacturing industry^[137] in Europe are listed in Table 6-2.

¹³⁶ CEMBUREAU. 2006. Air emissions and alternative fuels in the European cement industry

¹³⁷ European Commission. 2009. Integrated Pollution Prevention and Control Draft Reference Document on Best Available Techniques in the Cement, Lime and Magnesium Manufacturing Industries

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 6: Emissions from Use of Refuse Derived Fuel

Table 6-2: Alternative Fuels Regulatory Requirements/Guidelines for Cement Kilns

		Austria		Switzerland	Germany	Finland			Sweden		Lebanon	United States
		MSW (25 MJ/kg)	Plastic, paper, textile, wood waste	MSW - 25 MJ/kg	Plastic, paper, textile, wood waste	RDF Class I	RDF Class II	RDF Class III	Specialbränsle A	Lattbränsle		
Chlorine	%	1	2	–	1.5	0.15	0.50	1.5	1.0	1.0	–	–
Antimony (Sb)	mg/kg	5	20	5	120	–	–	–	–	–	–	50
Arsenic (As)	mg/kg	15	15	15	13	–	–	–	–	–	10	50
Beryllium (Be)	mg/kg	5	–	5	2	–	–	–	–	–	2	–
Cadmium (Cd)	mg/kg	2	27	2	9	1.0	4.0	5.0	10	5	5	40
Chromium (Cr)	mg/kg	100	300	100	250	–	–	–	300	30	–	200
Copper (Cu)	mg/kg	100	500	100	700	–	–	–	–	–	150	600
Lead (Pb)	mg/kg	200	500	200	400	–	–	–	350	100	100	500
Mercury (Hg)	mg/kg	0.5	2	0.5	1.2	0.1	0.2	0.5	–	5	1	20
Nickel (Ni)	mg/kg	100	200	100	160	–	–	–	–	10	50	50
Thallium (Tl)	mg/kg	3	10	3	2	–	–	–	–	–	2	40
Tin (Sn)	mg/kg	10	70	10	70	–	–	–	–	–	70	100
Vanadium (V)	mg/kg	100	–	100	25	–	–	–	–	50	20	50
Zinc (Zn)	mg/kg	400	–	400	–	–	–	–	2000	–	–	1000

NOTE:

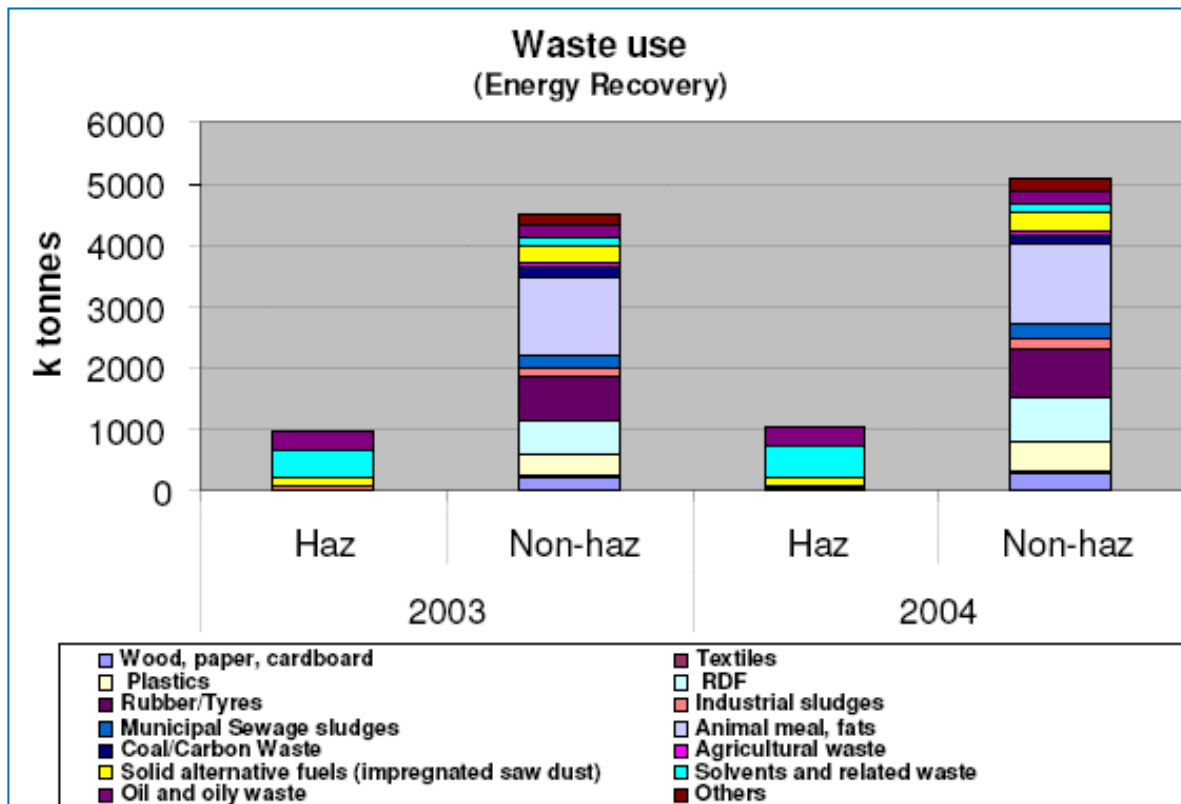
“–” indicates that no regulated value has been set for that parameter by that jurisdiction.

Table 6-3: Types of Alternative Fuels Used in the European Cement Industry

Types of Waste Fuels (Hazardous and Non-Hazardous)	
Wood, paper, cardboard	Municipal sewage sludge
Textiles	Animal meal, fats
Plastics	Coal/carbon waste
Processed MSW fractions (e.g., RDF)	Agricultural waste
Rubber/tires	Solid waste (impregnated sawdust)
Industrial Sludge	Solvents and related waste
Oil and oily waste	

Figure 6-1 illustrates the consumption of different types of hazardous and non-hazardous waste used as fuel in cement kilns in the EU-27 in 2003 and 2004.

Figure 6-1: Consumption of Different Types of Hazardous and Non-hazardous Waste Used as Fuels in Cement Kilns in the EU-27



Source: European Commission. 2009. Integrated Pollution Prevention and Control Draft Reference Document on Best Available Techniques in the Cement, Lime and Magnesium Manufacturing Industries

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 6: Emissions from Use of Refuse Derived Fuel

Characteristics of the cement production process lend itself to beneficial waste-to-energy and material recycling applications. The following is a list of characteristics of cement production which lend it to the beneficial use of waste materials as fuel:

- Maximum temperatures of approximately 2,000°C (main firing system, flame temperature) in rotary kilns
- Gas retention times of about 8 seconds at temperatures above 1,200°C in rotary kilns
- Material temperatures of about 1,450°C in the sintering zone of the rotary kiln
- Oxidising gas atmosphere in the rotary kiln
- Gas retention time in the secondary firing system of more than two seconds at temperatures of above 850°C; in the precalciner, the retention times are correspondingly longer and temperatures are higher
- Solids temperatures of 850°C in the secondary firing system and/or the calciner
- Uniform burnout conditions for load fluctuations due to the high temperatures at sufficiently long retention times
- Destruction of organic pollutants due to achievement of high temperatures at sufficiently long retention times
- Sorption of gaseous components like HF, HCl, SO₂ on alkaline reactants
- High retention capacity for particle-bound heavy metals
- Short retention times of exhaust gases in the temperature range known to lead to 'de novo-synthesis' of dioxins and furans
- Complete utilization of fuel ashes as clinker components and hence, simultaneous material recycling (e.g., also as a component of the raw material) and energy recovery
- Product specific wastes are not generated due to a complete material utilization into the clinker matrix; however, some cement plants in Europe dispose of bypass dust
- Chemical-mineralogical incorporation of non-volatile heavy metals into the clinker matrix.^[138]

Emissions control in cement kilns is largely based on the use of bag houses to capture particulate matter from the flue gas (which also controls emissions of most heavy metals as discussed below). More modern facilities or retrofitted plants may be equipped with NO_x control, specifically SNCR. Emissions of other parameters such as POPs or acid gases are generally controlled through the operating characteristics of cement facilities as noted above. Monitoring of cement plant emissions generally includes CEMs (for parameters such as NO_x, SO_x, CO, TOC etc.) which serve a dual purpose in both monitoring emissions and determining if the facility is operating appropriately within the parameters required to manufacture quality cement product. Periodic stack testing is usually also required both to ensure effective calibration of the CEMs and to establish performance against regulated ELVs for a broader range of parameters.

¹³⁸ European Commission. 2009. Integrated Pollution Prevention and Control Draft Reference Document on Best Available Techniques in the Cement, Lime and Magnesium Manufacturing Industries

The impact on emissions from cement manufacturing due to the use of waste materials as alternative fuels or alternative raw materials is relatively minor. The following bullet list summarizes the assumed impacts as outlined by the European Commission.^[139]

- Dust emissions remain unaffected by using wastes.
- The use of suitable waste has only a minor influence on metal emissions due to the high retention of metals in the finished product. Non-volatile metals tend to be bound almost entirely in the clinker matrix. Semi-volatile metals such as lead or cadmium tend to be captured in the clinker stream or in dust. Highly volatile metals such as mercury and thallium tend to be of greater concern as they tend to vapourize and leave the kiln system. For this reason, it is important to limit the amount of highly volatile metals in the waste being used.
- NO_x, HCl, HF, SO₂, CO, and TOC are largely unaffected.
- The combustion conditions in rotary kiln systems ensure low emissions concentrations of dioxins and furans. The biggest factor impacting these emissions is what location waste materials are fed into the system (i.e., wastes that are fed into the main firing system tend to reach high enough temperatures and retention times to limit dioxin/furan emissions while wastes fed into the secondary firing zone may not reach high enough temperatures or long enough retention times).

Table 6-4 provides an example of the impact that utilizing waste as a fuel source could have on the emission profile from a typical cement kiln. Note: while the report cited does not specify the original sources of the waste in each application, RDF generation in Germany is generally derived from processing MSW materials (not including specialized waste streams such as construction/demolition material). Also it should be noted that while the monitoring approach for each parameter is not noted, cement kilns in the EU and North America typically use CEMs for parameters such as SO_x and NO_x and periodic stack testing for other parameters (PAHs, metals). As the table illustrates, utilizing waste as a fuel has a minimal impact on the emissions released from the plant, with some parameters decreasing and others increasing within the same order of magnitude.^[140]

Table 6-4: Emission Profile from a Cement Kiln Using RDF

Parameter	Measure	Individual Measurements	
		No Utilization of Wastes	Utilization of Wastes
Total Particulate	mg/m ³	2.8 – 12.9	12.0 – 15.9
HCl	mg/m ³	0.88 – 5.93	0.87 – 1.32
SO _x	mg/m ³	714 – 878	311 – 328
HF	mg/m ³	0.13 – 0.23	0.02 – 0.04
NO _x	mg/m ³	789 – 835	406 – 560

¹³⁹ European Commission. 2009. Integrated Pollution Prevention and Control Draft Reference Document on Best Available Techniques in the Cement, Lime and Magnesium Manufacturing Industries

¹⁴⁰ UBA. 2001. Draft of a German Report with basic information for a BREF-Dokument "Waste Incineration". Umweltbundesamt

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 6: Emissions from Use of Refuse Derived Fuel

Parameter	Measure	Individual Measurements	
		No Utilization of Wastes	Utilization of Wastes
Total C	mg/m ³	11.7 – 23.2	5.7 – 7.1
PAHs	mg/m ³	–	0.0026
Benzene	mg/m ³	0.27 – 0.54	0.45 – 0.55
Cd	mg/m ³	<0.005	<0.007
Tl	mg/m ³	<0.005	<0.005
Hg	mg/m ³	0.014 – 0.044	0.003 – 0.006
Sum of Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V, Sn	mg/m ³	<0.3	<0.5
PCDD/PCDF, I-TEQ	mg/m ³	0.001 – 0.002	0.005 – 0.0065

The following sections provide an overview of the regulatory framework governing the use of waste as a raw material or alternative fuel in cement kilns in Ontario and the European Union.

6.3.1 Regulatory Approach in Ontario

Guideline A-7 (October 2010) applies to all thermal treatment facilities processing municipal waste including manufacturing facilities such as cement and lime kilns, if they use municipal waste as an alternative fuel. The Guideline sets out specific in-stack emission limits for cement and lime kilns which take into account operational differences for these facilities as compared to other “dedicated” thermal treatment facilities (see the following table).

Table 6-5: Emission Limits for Existing Cement and Lime Kilns Burning Municipal Waste (Guideline A-7)

Parameter	In-Stack Emission Limit	Verification of Compliance ⁷
Particulate Matter (PM)	50 mg/Rm ³ or a site specific emission limit where a more stringent stack concentration limit is already in place for existing raw materials and conventional fuels ¹	Results from compliance source testing or calculated as the rolling arithmetic average of four (4) hours of data measured by a continuous emission monitoring system that provides data least once every fifteen minutes
Cadmium (Cd)	7 µg/Rm ³ unless existing raw materials and conventional fuels result in higher concentration ²	Results from compliance source testing (periodic stack testing)
Lead (Pb)	60 µg/Rm ³ unless existing raw materials and conventional fuels result in higher concentration ²	Results from compliance source testing (periodic stack testing)
Mercury (Hg)	20 µg/Rm ³ unless existing raw materials and conventional fuels result in higher concentration ²	Results from compliance source testing (periodic stack testing) or calculated as the rolling arithmetic average of 24 hours of data measured by a continuous emission monitoring system that provides data at least once every 15 minutes

Parameter	In-Stack Emission Limit	Verification of Compliance ⁷
Dioxins and Furans	80 pg/Rm ³	Results from compliance source testing (periodic stack testing); results expressed as I-TEQ
Hydrochloric Acid (HCl)	18 ppm _{dv} (27 mg/Rm ³) unless existing raw materials and conventional fuels result in higher concentration ³	Calculated as the rolling arithmetic average of 24 hours of data measured by a continuous emission monitoring system that provides data at least once every 15 minutes
Sulphur Dioxide (SO ₂)	Site specific limit not to exceed the in-stack SO ₂ concentration resulting from existing raw materials and conventional fuels. ^{4,6}	Calculated as the rolling arithmetic average of 24 hours of data measured by a continuous emission monitoring system that provides data at least once every 15 minutes
Nitrogen Oxides (NO _x)	Site specific limit not to exceed the in-stack NO _x concentration resulting from existing raw materials and fossil fuels ^{5,6}	Calculated as the rolling arithmetic average of 24 hours of data measured by a continuous emission monitoring system that provides data at least once every 15 minutes
Organic Matter	Section 50 of Ontario Regulation 419/05	Calculated as the rolling arithmetic average of 10 minutes of data measured by a continuous emission monitoring system that provides data at least once every minute
Opacity	Section 46 of Ontario Regulation 419/05	Calculated as the rolling arithmetic average of six (6) minutes of data measured by a continuous opacity monitor that provides data at least once every minute

NOTES:

- 1) If there is no limit for particulate matter in an existing Certificate of Approval issued to the facility, the limit of 50 mg/Rm³ can be expected to be included in the Certificate of Approval that will allow burning of municipal waste as an alternative fuel. Where a more stringent site-specific limit for particulate matter is already incorporated into an existing Certificate of Approval for manufacturing of cement or lime using existing raw materials and conventional fuels, the existing limit will be retained if it is more stringent than 50 mg/Rm³.
- 2) Limits for cadmium, lead and mercury can be expected to be included in a Certificate of Approval that will allow burning of municipal waste as an alternative fuel, unless the proponent can demonstrate that one or more of the specified metals are present in the existing raw materials and conventional fuels in such a quantity that the relevant limit(s) would be exceeded without the use of municipal waste as a fuel. In such a case, site-specific limits for one or more of the above metals may be established and incorporated into a Certificate of Approval. The site specific limits can be expected to be developed based on a review of relevant facility specific data that includes information on the discharge of cadmium, lead, and/or mercury from the facility (e.g., source testing data, analytical data for raw materials, mass balance calculations). Such site specific limits will take into account the variability of the raw material composition.
- 3) It is expected that cement and lime kilns can comply with the hydrogen chloride (HCl) limit. A site-specific emission limit for HCl may, however, be incorporated into a Certificate of Approval based on HCl concentrations when using existing raw materials and conventional fuels. This will prevent any increase in HCl emissions resulting from use of municipal waste as fuel for the kiln.
- 4) A site-specific emission limit for sulphur dioxide (SO₂) can be expected to be incorporated into a Certificate of Approval based on SO₂ concentrations when burning conventional fuels. This will prevent any increase in SO₂ emissions resulting from use of municipal waste as fuel for the kiln. For kilns required to use continuous emission monitoring (or a method that will provide estimates of emissions that are at least as accurate as the estimates that would be provided by a continuous emission monitoring system) for SO₂ under Ontario Regulation 194/05 (Industry Emissions – Nitrogen Oxides and Sulphur Dioxide), the limit will be determined based on a review of a minimum of 6-months of Continuous Emission Monitoring System (CEMS) data (or data obtained using another method) for the kiln (1-hour, 24-hour and 30-day SO₂ averages in ppm_{dv} or mg/Rm³). The Ministry will continue to monitor the development of SO₂ control technology worldwide. As new proven technology is developed suitable for this industry sector, the Ministry will review this guideline to determine if limits can be adjusted.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 6: Emissions from Use of Refuse Derived Fuel

- 5) A site-specific emission limit for oxides of nitrogen (NO_x) can be expected to be incorporated into a Certificate of Approval based on NO_x concentrations when burning conventional fuels. This will prevent any increase in NO_x emissions resulting from use of municipal waste as fuel for the kiln. For kilns required to use continuous emission monitoring (or a method that will provide estimates of emission that are at least as accurate as the estimates that would be provided by a continuous emission monitoring system) for NO_x under Ontario Regulation 194/05, the limit will be determined based on a review of a minimum of 6-months of CEMS data (or data obtained using another method) for the kiln (1-hour, 24-hour and 30-day NO_x averages in ppm_{dv} or mg/Rm³). The Ministry will continue to monitor the development of NO_x control technology worldwide. As new proven technology is developed suitable for this industry sector, the Ministry will review this guideline to determine if limits can be adjusted.
- 6) Lime kilns that do not currently have CEMS for SO_2 , and NO_x , can be expected to carry out a monitoring program to determine the normal ranges for the parameters when burning conventional fuels. The proponent of an alternate fuel should consult staff of the Ministry when planning such a program. The results of the monitoring program are expected to be included with an application for a Certificate of Approval to burn municipal waste as an alternate fuel.
- 7) Compliance source testing as set out in the facility's Certificate of Approval. Owners and operators of cement and lime kilns can expect to be required, by conditions in Certificates of Approval, to maintain CEMS for SO_2 , NO_x , THC, HCl and opacity.

The approach used in Ontario clearly acknowledges that it is not reasonable to apply exactly the same ELVs to cement or lime kilns that use a waste derived fuel. Rather the approach that is taken applies the same stack limits applied to WTE facilities, for parameters that are directly associated with fuel quality (e.g., heavy metals, POPs) but not for emission parameters that are driven largely by the primary purpose and design of the facility (SO_x , NO_x , PM). For some heavy metals (mercury, cadmium and lead) it is also recognized that the contribution from the raw material stream for some of these trace metals can be more significant than from the fuels, and in those cases site specific ELVs are set.

In order to use RDF as a fuel in Ontario, industrial facilities have to apply for or amend their operating permits (certificates of approval) issued under the *Environmental Protection Act* (EPA). The permitting/application process generally involves the following:

- Fuel testing and comparison of the RDF fuel quality against the conventional fuels. Mass balance analyses are generally used to establish any potential shift in emissions concentrations that could result from the use of the fuels.
- Determination of the appropriate RDF feed rate, based on the outcome of the analysis above and based on review of the impact of various fuel characteristics (e.g., heat value).

The approach used for proposed RDF applications has been to encourage and permit the use of RDF for a fuels test/trial run, the results of which are used to demonstrate that RDF can be used within the current ELVs established for the facility and/or to determine site specific ELVs for various parameters that would apply during regular use of the RDF.

6.3.2 European Union

As noted previously, the use of waste fuels in the manufacture of cement is commonly practiced in Europe. On average, alternative fuels were substituted for 17% of conventional fuels in the

manufacture of cement in EU-23 countries (in 2007). This rate of substitution is equivalent to saving about 4 million tonnes of coal.^[141] For some facilities, the rate of substitution can be as high as 100%.

Two directives apply to the use of waste in cement manufacturing in the EU, namely the Integrated Pollution Prevention and Control Directive (Directive 2008/1/EC) and the Waste Incineration Directive (Directive 2000/76/EC).

The IPPC Directive applies to installations for the production of cement clinker in rotary kiln with a production capacity exceeding 500 tonnes per day.^[142] As discussed previously, the IPPC is aimed at minimizing the emissions of pollutants from large industrial installations through the use of an environmental permit. Permits contain emission limit values (ELVs) and set conditions based on the application of best available technology (BAT). The permits also address energy efficiency, waste minimization, prevention of accidental emissions, and site restoration.^[143] If a cement manufacturing operation uses waste derived fuel or raw materials derived from waste, the facility would still be required to emission limit values (ELVs) set out in its permit.

In May, 2009, the European Commission released a draft reference document on the best available techniques in the cement, lime, and magnesium oxide manufacturing industries. The document goes into considerable detail concerning the use of waste as alternative raw material and fuel in cement manufacturing. The following table (Table 6-6) provides a summary of the best available techniques for the cement industry relating to the use of wastes.^[144]

Table 6-6: Summary of BAT for the Cement Industry Relating to the Use of Wastes

Safety management for the use of hazardous waste materials	<ul style="list-style-type: none"> Apply safety management for the handling, e.g., storage, and/or feeding of hazardous waste materials, such as using a risk based approach according to the source and type of waste, for the labelling, checking, sampling and testing of waste to be handled
Waste Quality Control	<ul style="list-style-type: none"> Apply quality assurance systems to guarantee the characteristics of wastes and to analyse any waste that is to be used as raw material and/or fuel in a cement kiln for parameters/criteria (constant quality, physical criteria, chemical criteria). Control the amount of relevant parameters for any waste that is to be used as raw material and/or fuel in a cement kiln, such as chlorine, relevant metals (e.g., cadmium, mercury, thallium), sulphur, total halogen content Apply quality assurance systems for each waste load

¹⁴¹ CEMBUREAU. 2006. 2004 and 2005 statistics on the use of alternative fuels and materials in the clinker production in the European cement industry

¹⁴² EEF: Integrated Pollution Prevention and Control (IPPC). 2009. [http://www.eef.org.uk/policy-media/policy-briefs/briefings/Integrated-Pollution-Prevention-Control-\(IPPC\).htm](http://www.eef.org.uk/policy-media/policy-briefs/briefings/Integrated-Pollution-Prevention-Control-(IPPC).htm)

¹⁴³ EEF: Integrated Pollution Prevention and Control (IPPC). 2009. [http://www.eef.org.uk/policy-media/policy-briefs/briefings/Integrated-Pollution-Prevention-Control-\(IPPC\).htm](http://www.eef.org.uk/policy-media/policy-briefs/briefings/Integrated-Pollution-Prevention-Control-(IPPC).htm)

¹⁴⁴ European Commission. 2009. Integrated Pollution Prevention and Control Draft Reference Document on Best Available Techniques in the Cement, Lime and Magnesium Manufacturing Industries

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 6: Emissions from Use of Refuse Derived Fuel

Waste feeding into the kiln	<ul style="list-style-type: none"> Use the appropriate feed points to the kiln in terms of temperature and residence time depending on kiln design and kiln operation Feed waste materials containing organic components that can be volatilised before the calcining zone into the adequately high temperature zones of the kiln system Operate in such a way that the gas resulting from the co-incineration of waste is raised in a controlled and homogeneous fashion, even under the most unfavourable conditions, to a temperature of 850°C for two seconds Raise the temperature to 1,100°C, if hazardous waste with a content of more than 1% of halogenated organic substances, expressed as chlorine, is co-incinerated Feed wastes continuously and constantly Stop co-incinerating waste for operations such as start-ups and/or shutdowns when appropriate temperatures and residence times cannot be reached
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The IPPC Directive also provides BAT for emissions limits from cement manufacturing. The following table provides the emissions limit values as laid out in the document.

Table 6-7: BAT Emissions Limits for Cement Manufacturing in the IPPC Directive

Contaminant	Concentration Units	Integrated Pollution Prevention and Control Directive (2008/1/EC)
Total Particulate Matter (TPM) ¹	mg/Nm ³	<10 – 20
Hydrogen Chloride (HCl)	mg/Nm ³	10
Sulphur Dioxide (SO ₂)	mg/Nm ³	<50 – <400 ⁴
Hydrogen Fluoride (HF)	mg/Nm ³	1
Nitrogen Oxides (NO _x) (pre-heater kilns)	mg/Nm ³	<200 – 4,502 ³
Nitrogen Oxides (NO _x) (lepol and long rotary kilns)		400 – 800
Mercury (Hg) ⁶	ug/Nm ³	<0.05
Cd + Tl ⁶	ug/Nm ³	<0.05
Sum (Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V) ⁶	ug/Nm ³	<0.5
PCDD/F TEQ (I) (Dioxins and Furans) ⁵	ng/Nm ³	<0.05 – 0.1

NOTES:

Under the following conditions: 273 K, 101.3 kPa, 10% Oxygen, Dry Gas. Daily average values unless otherwise noted.

¹ Dust emissions from kiln firing processes – when applying a fabric filter or new or upgraded ESP, the lower level is achieved.

² BAT-AEL is 500 mg/Nm³, where after primary measures/techniques the initial NO_x level is >1000 mg/Nm³

³ Existing kiln system design, fuel mix properties including waste, raw material burnability can influence the ability to be in the range. Levels below 350 mg/Nm³ are achieved at kilns with favourable conditions. The lower value of 200 mg/Nm³ has only been reported as monthly average for three plants (easy burning mix used)

⁴ Range takes into account the sulphur content in the raw materials

⁵ Average over the sampling period (6 – 8 hours)

⁶ Average over the sampling period spot measurement, for at least half an hour.

The Waste Incineration Directive also applies to cement manufacturing facilities that utilize waste as a feedstock. The WID defines cement facilities that utilize waste as “co-incineration” plants. A “co-

incineration plant” is defined in the Directive as any stationary or mobile plant whose main purpose is the generation of energy or production of material products and:

- Which uses waste as a regular or additional fuel, or
- In which waste is thermally treated for the purpose of disposal.

The Directive states that no “co-incineration plant” shall operate without a permit from the appropriate governing agency. The permit must outline a number of specific parameters including ensuring that cement facility is properly designed and is using the appropriate equipment. Further, the permit must list the categories of waste to be treated and the quantities of waste to be treated, include the total waste co-incinerating capacity of the plant, and specify the sampling and measurement procedures to satisfy the obligations imposed for periodic measurements of each air and water pollutants.

If the cement facility is to treat hazardous materials, the permit has to also outline the quantities of different categories of hazardous waste that may be treated and the minimum and maximum mass flows of those hazardous wastes, their lowest and maximum calorific values and their maximum concentration of pollutants (e.g., PCB, chlorine, heavy metals).

The Directive also provides guidance concerning the reception and delivery of waste at the facility so as to limit the effects on the environment and direct risks to human health. It states that the facility operator shall determine the mass of each category of waste prior to accepting the material on site. For hazardous waste, the facility should obtain the physical and as far as practicable chemical composition of the waste as well as the hazardous characteristics of the waste.

The Directive goes on to state that co-incineration plants need to be designed and operated in such as way that waste is treated at a temperature of 850°C for two seconds, (or 1,100°C if the waste has more than 1% of halogenated organic substances) which is the same requirement for a regular waste incineration plant.

The air emissions limit values set out in the Directive for co-incineration plants are slightly different than those set out for incineration plants. The co-incineration plant must be designed, equipped, built and operated in such as way that the emission limit values set out in the following table are not exceeded in the exhaust gas. The primary difference in the WID in regards to emissions from co-incineration plants is that the ELV for NO_x is set significantly higher than that for WTE facilities.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 6: Emissions from Use of Refuse Derived Fuel

Table 6-8: Emissions Limit Values for Cement Kilns in the Waste Incineration Directive

Contaminant	Concentration Units	Waste Incineration Directive (2000/76/EC)
Total Particulate Matter (TPM)	mg/m ³	30
Hydrogen Chloride (HCl)	mg/m ³	10
Sulphur Dioxide (SO ₂) ¹	mg/m ³	50
Hydrogen Fluoride (HF)	mg/m ³	1
Nitrogen Oxides (NO _x) (existing plants)	mg/m ³	800
Nitrogen Oxides (NO _x) (new plants)		500
TOC ¹	mg/m ³	10
Mercury (Hg)	µg/m ³	0.05
Cd + Tl	µg/m ³	0.05
Sum (Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V)	µg/m ³	0.5
PCDD/F TEQ (I) (Dioxins and Furans)	ng/m ³	0.1

NOTES:

Under the following conditions: 273 K, 101.3 kPa, 10% Oxygen, Dry Gas

¹ Exemptions may be authorized by a competent authority in cases where these emissions do not result from the incineration of waste

6.4 Proposed Regulatory Approach for RDF

The preceding sections discuss use of RDF by two industrial sectors, for which there is current and general interest in the use of alternative solid fuel materials. Pulp mill/wood fired boilers and cement kilns are not the only industrial sectors where there could be future interest in the use of RDF for co-firing or co-incineration. A consistent regulatory approach that addresses use of RDF by any industry sector is required.

Reviewing the regulatory approach applied in various jurisdictions to the use of RDF as a fuel for co-firing or co-incineration along with current experience with RDF applications in BC, indicates that a reasonable approach to mitigating the risk associated with the use of waste derived fuels would consist of the following:

- Generally when looking across the spectrum of RDF use in co-combustion (some examples of which are discussed above) the RDF usually has the same general characteristics as the conventional fuels used by the facilities. For example, wood fired boilers generally use RDF that is similar in composition (e.g., primarily cellulosic) to conventional wood waste. Cement kilns use a wide range of RDF fuels including waste plastics, given that the conventional fuels used by these facilities are fossil fuel based.

- It would be reasonable to define which waste materials are considered 'waste derived' fuels which would require major modifications and permit amendments, and those that would be considered equivalent to current fuels. For example, as discussed above, it would be reasonable to set a definition for 'clean' wood waste that could be separated from construction and demolition waste for use in wood fired boilers as part of their regular fuel stream and 'contaminated' wood waste that would require major modifications and permit amendments. The BC MOE should develop definitions and potentially RDF fuel specifications similar to those used in other jurisdictions relative to RDF for cement applications. These definitions/specifications and/or proponent driven specifications would be set out in the amended air emission permits.
- Testing of RDF will be required generally either to demonstrate compliance with a regulatory limit for fuel quality and/or to ensure that the fuel falls within the range of specifications required to ensure that the material can be used without compromising the operations of the facility proposing to use RDF as a full or partial fuel substitute. The results of fuel tests would be reported in the application process for regulatory approval, and compared against the quality of the conventional fuels used at the facility. These results could be used to determine through a mass balance analysis if the contribution of parameters in the RDF would result in a shift in emissions concentrations if the RDF was used (e.g., presence of chlorine shifting the emissions concentration of HCl).
- Fuel trials should be undertaken to demonstrate that the proposed RDF can be effectively used as fuel, and to establish site/facility specific ELVs where applicable. Fuel trials will also allow for the facility operator to review standard operations and to determine the appropriate adjustments needed to use RDF effectively as a fuel. Fuel trials should reflect the proposed RDF substitution rates, so that the proponent can demonstrate how at the maximum proposed fuel substitution rate the facility will comply with current and/or proposed ELVs.
- Generally within the air emission permits, the same stack limits (ELVs) would be applied to industrial facilities that use RDF as would be applied to WTE facilities (as set out in Section 8.3), for parameters that are directly associated with fuel quality (e.g., heavy metals, POPs) but not for emission parameters that are driven largely by the primary purpose and design of the facility. For wood fired boilers, design parameters would include parameters such as NO_x and CO, while for cement kilns this would include a broader spectrum of parameters (SO_x, NO_x, CO, TOC, particulates) that are driven by raw material quality and standard facility design.
- Once permitted, facilities would have to implement quality assurance systems to guarantee the characteristics of the RDF and to analyze the RDF for key parameters/criteria including consistency, physical criteria (related to suitability for use at the facility) and chemical criteria (related to ELV compliance). Generally, RDF would have to be tested at random at least quarterly within the first few years of operation. Results from the quality assurance systems would be included with in annual compliance reporting.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 6: Emissions from Use of Refuse Derived Fuel

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7 ASSOCIATED COSTS AND ENERGY EFFICIENCY

This section investigates the capital and operating costs for WTE and discusses the energy efficiency associated with WTE facilities and potential revenues associated with energy recovery.

7.1 Capital Expenditure and Operating Costs

This subsection provides a summary of current capital and operating costs for the majority of thermal treatment technologies. These are expressed as capital cost per annual design tonne (commonly used for capital cost comparison) and operating costs per annual design tonne. The data presented is based on financial information from jurisdictions in which thermal treatment approaches have been implemented and financial information made available directly from technology vendors.

The range of capital and operating costs reported by individual vendors are influenced by the unique circumstances associated with siting a facility, such as jurisdictional constraints, size of facility, and the form in which the energy is recovered and used. This summary therefore includes:

- i. The potential range of order of magnitude costs, identifying the key factors for both the low and high end of the range and the median values for both capital and operating costs for various technologies.
- ii. Where available, the cost differentials between these technologies and the factors which contribute to these differences.
- iii. Costs specifically associated with the applicable emissions control and/or thermal process control options.

Identification of costs in a North American context can be quite difficult. Few new facilities have reached the stage of development in either Canada and the USA and for proposed facilities, either the financial information is proprietary (particularly if the proposed facility is intended to be owned/operated by a private sector entity) or may not be based on guaranteed pricing through formal procurement processes.

Implementation of projects in North America can be based on a variety of contractual arrangements, each of which has the potential to affect the potential costs and allocation of risk between the technology vendor and the owner/operator of the plant. Some of the typical contractual arrangements for such facilities include:

- **Design/Build:** the intended owner/operator (e.g., municipality) seeks pricing for design and construction of the facility. In such a context the majority of the risk is borne by the owner/operator.
- **Design/Build/Operate:** the intended owner seeks a contract from a technology vendor (usually consortium representing proprietary technology vendors, construction firms and an operating entity) to design and build the facility and to operate the plant for a fixed period of time. Often the owner passes on some of the risk associated with the facility through performance guarantees that have to be met by the preferred vendor.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 7: Associated Costs and Energy Efficiency

- **Design/Build/Finance/Operate (P3):** the intended owner seeks a contract similar to that noted above, wherein the vendor also holds a financing role, seeking return on the investment in the capital cost for the facility over a longer contractual period. Generally, there is increased sharing of risk and concomitant increases in overall unit costs.
- **Design/Build/Own/Operate:** the party requiring capacity for WTE seeks pricing for the use of WTE capacity that is entirely owned/operated/financed by the vendor. These arrangements can be coupled with the provision of some assistance in the form of siting, provision of infrastructure etc. between the parties. Generally long-term fixed “put or pay” contracts are necessary to guarantee revenues to the vendor. Such contracts guarantee that the vendor will receive a set minimum revenue value, associated with a set minimum waste supply. Should the generator not have sufficient waste supply, it is still required to pay the vendor the set minimum fee. Also, generally the unit cost for use of the WTE capacity would be higher given that the risk is almost entirely borne by the vendor.

The potential capital and operating costs and net costs can vary significantly for all WTE technologies as noted in the range of order of magnitude costs as discussed below. Factors that affect the range of costs for conventional combustion as noted below could also be considered to affect the costs for the other technologies as the same considerations would apply.

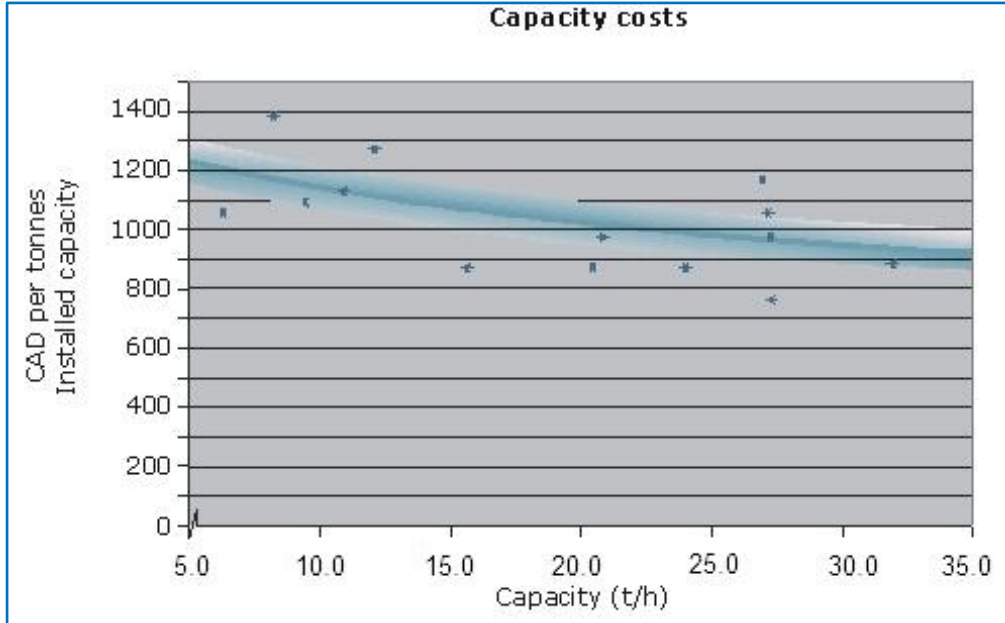
7.1.1 Range of Order of Magnitude Costs

In Figure 7-1, the effect of the size of the WTE plant on the capital costs per tonne of waste are illustrated. The curve shown is based on known capital costs for a wide range of new European Energy from Waste lines, in which Ramboll has been involved during the last 10 years. The background data from 14 European Energy from Waste plants is shown as dots (stars) on the Figure. The background data are actual capital costs adjusted to 2006 price level.

As seen from Figure 7-1, the capital costs per tonne of waste based on European price level are generally \$900 – \$1,200 per tonne of installed capacity. The capital costs between a small (5 tph) and a large (30 tph) incineration plant differs by about 25% (on a cost per throughput tonne basis).

The background data indicated on Figure 7-1 shows that the capital costs differs significantly even for plants of similar size and erected in the same country. This variation indicates that when looking at a preliminary overall level, the capital costs for WTE plants can only be roughly estimated.

Figure 7-1: Comparison of Capital Costs for WTE Facilities per Installed Capacity



Source: Ramboll. 2007. Memo to MacViro during the Durham/York Environmental Assessment

It should be noted that the capital costs noted exclude the purchase of a site and exclude external infrastructure like roads, water, electricity/grid connections, etc. outside the premises of the site.

The capital costs can be split into different components. In Table 7-1 the total capital costs are split into five main components or parts. For each main component, the percentage of the total capital costs related to the specific component is shown. The proposed distribution of capital costs between the different components is based on the general experience with the European market. Of course large variations within the distribution of capital costs between the different main components are foreseen. Furthermore, there might be some differences between the North American market and the European market which will influence the distribution of the total capital costs between the different components/parts. However, the shown distribution can be generally assumed.

Table 7-1: General Distribution of WTE Total Capital Costs

Component	Percentage of Capital Costs
Thermal processing equipment (incinerator/boiler)	40%
Energy production equipment (turbines and generators)	10%
APC system (flue gas treatment)	15%
Building (civil works)	25%
Miscellaneous (approvals, general site works, ash processing, electrical transmission and interconnect etc.)	10%

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

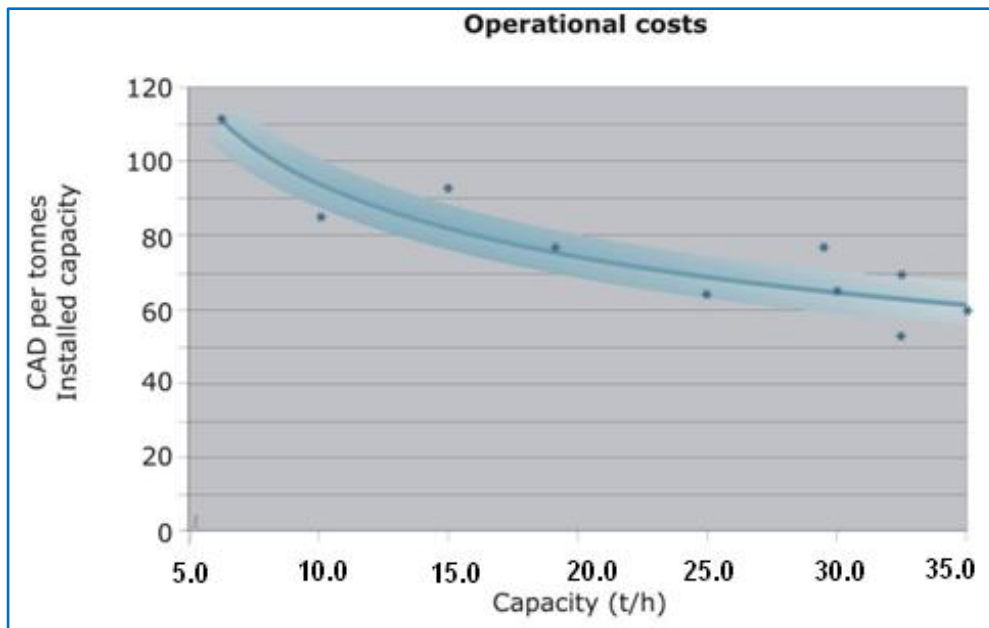
Final Report

Section 7: Associated Costs and Energy Efficiency

When estimating the operational costs of WTE facilities, the size of the plant will influence the total costs in the same way as indicated for the capital costs. Furthermore, the total operational costs are to a large extent affected by local conditions such as local labour costs and the cost of consumables.

In Figure 7-2, the effect of the size of the plant on the operational costs per tonne of waste is illustrated. The curve shown is based on estimated operational costs for a range of new or planned European Energy from Waste lines. It is important to be aware that the background data are mainly estimates based on local conditions related to each plant. This includes e.g., type of APC-system, transport-expenses for the residues and the degree of automation of the plant (cranes, gate-control and weighting of incoming waste and outgoing residues etc.). It should also be noted that Figure 7-2 provides information related to gross operating costs, and thus does not take into account income from the sale of energy.

Figure 7-2: Range of Operational Costs for WTE Facilities in the EU



Source: Ramboll. 2007. Memo to MacViro during the Durham/York Environmental Assessment

As seen from Figure 7-2, the operational costs per tonne of waste based on European price level are generally \$60 – \$90 per tonne of installed capacity. The operational costs between a small (6 tph) and a large (35 tph) incineration plant differs by almost 50% (on a cost per throughput tonne basis). The operational costs can be split into different components as indicated:

- Labour and administration 25 – 30%
- Maintenance 35 – 40%
- Utilities and supplies – 20%
- Residues (management and disposal) – 20%.

The following sections discuss the potential range in capital and operating costs for the various WTE technologies presented in Section 2, based on publicly reported data.

7.1.1.1 Conventional Combustion

Capital costs were estimated based on five project estimates found during the literature review.^{[145],[146],[147],[148],[149]} The highest reported cost was \$1,684/annual design tonne (assuming a 200,000 tonne per year capacity where applicable, 2009 CDN\$). The lowest reported cost was \$640/annual design tonne. The median capital cost was \$771/annual design tonne with a standard deviation of 50.27%. For new WTE facilities a certain, and often high capital cost is incurred to improve the architectural appearance of the plant and makes investment costs difficult to compare. In most European countries the APC plant is placed in a building, whereas in North America this has not been the common practice.

Operating costs were also calculated. The maximum reported operating cost/tonne was \$105 and the minimum was \$38.90. The median operating cost/tonne was \$64.09 with a standard deviation of 36%.

These reported values are within the range of true capital and operating costs incurred in many jurisdictions that have been guaranteed through contractual arrangements.

The differences in capital and operating costs between conventional combustion facilities often reflect the following:

- **Size:** economies of scale indicate that larger facilities tend to have lower capital and operating costs per annual design tonne. For example, an Austrian study found that based on recently incurred costs in other EU nations that as the throughput of a WTE facility tripled (from 100,000 to 300,000 tpy) the cost per tonne (operating and capital) for the front end systems to manage MSW and the back end systems to manage ash decreased by 28%.^[150] In regards to the firing system and boiler for such facilities, as the throughput doubled (from 75,000 to 150,000 tpy) the cost per tonne (operating and capital) decreased by 6%.
- **Configuration:** for example, a facility that includes a single 100,000 tpy mass burn combustion unit (boiler) would generally incur capital costs in the order of 25% (or more) less than a facility consisting of two 50,000 tpy combustion units.

¹⁴⁵ European Commission, Integrated Prevention and Control. 2006. Reference Document on Best Available Technology for Waste Incineration

¹⁴⁶ Confidential

¹⁴⁷ Jacques Whitford Stantec Limited. 2009. Durham/York Residual Waste Study Environmental Assessment

¹⁴⁸ MacViro. 2007. City of Ottawa REOI Report

¹⁴⁹ MacViro. 2007. County of Dufferin RFQ Process

¹⁵⁰ Austrian Federal Ministry of Agriculture and Forestry, Environment and Water Management –State of the Art for Waste Incineration Plants, Vienna November 2002

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 7: Associated Costs and Energy Efficiency

- **Architecture/Design:** a facility in a high profile location that would warrant special architectural treatments, additional landscaping and other design elements to reduce visual impacts, would generally incur capital costs in the order of 25 to 50% more than a facility located in an industrial zone with minimal requirements to improve the appearance of the facility.
- **APC Train:** as discussed further in this section, there are differences in both capital and operating costs associated with the APC trains suitable for such facilities.
- **Availability of Local Infrastructure:** WTE facilities generally require access to good transportation networks, electricity supply and access to the grid, supply of natural gas, supply of potable water and wastewater services.
- **Potential for Energy Utilization:** the net cost per tonne for WTE facilities declines based on the increased ability of the facility to sell energy. Generally, facilities that are able to sell heat directly to the market incur the lowest range of net costs per tonne, followed by facilities that are able to market both electricity and heat, with the facilities that incur the highest net cost per tonne being those that are only able to sell electricity. Furthermore, costs are affected by infrastructure required to access those markets, and the market price for electricity and heat. In a Canadian context, the ability to market heat at the present time is limited given that there are few policies and little initiative as yet to support district heating schemes. The ability of a WTE to market heat improves with access to industrial users of heat (steam) and/or new commercial/industrial areas where infrastructure for district heating could be considered.
- **Market price for Energy:** the market for energy from WTE varies significantly across North America and the globe, and is affected by energy policy and other legislative initiatives. For example, in jurisdictions such as many Scandinavian nations that have an energy policy that discourages dependence on fossil fuels, higher prices for electrical and heat energy are the norm. Energy pricing in jurisdictions such as Ontario, does not recognize the value of the energy from WTE in the same fashion as that from renewable sources such as biomass, although 50% or more of the energy from such facilities is usually derived from the biomass portion of the waste stream.

Table 7-2 compares two potential WTE facilities under consideration in Ontario, one of which represents the proposed facility for Durham/York Regions and the other representing a plant under consideration elsewhere in the Province. There is a significant difference in the capital costs that have been identified to-date for the two facilities, and some difference in the potential operating costs, based on some of the key factors noted above.

Table 7-2: Comparison of Capital Costs for Two Mid-Size WTE Facilities

	Durham/York 140,000 tpy, Mass Burn	Potential 100,000 to 200,000 tpy Mass Burn
Identified Capital Cost (2009\$)	\$1,500 to 1,700 per annual design tonne	\$900 to \$1,000 per annual design tonne
Identified Annual Operating Cost (2009\$)	\$100 to \$110 per annual design tonne	\$80 to \$90 per annual design tonne
Major Differences in Design	Two-unit facility (two 70,000 tpy mass burn combustion units, potential for two additional 70,000 tpy units) APC designed to achieve BAT EU and Ontario A-7 specifications High-profile location, Clarington Energy Park. Extensive architectural and landscaping treatment. Option for sale of electricity and heat through district heating/cooling.	One-unit facility (one 100,000 tpy mass burn combustion unit, potential for twinning in future) APC designed to meet Ontario A-7 guidelines. Low profile location in existing heavy industrial zone. Minimal architectural treatment or landscaping required. No option for district heating/cooling.
Similarities in Design	Reasonable access to local infrastructure (site servicing). Primary focus on sale of electricity, potential price 8 cents per kwh.	Site is fully serviced. Focus on sale of electricity, potential price 8 cents per kwh.

7.1.1.2 Gasification of MSW

Capital costs were estimated based on ten project estimates found during the literature review.^{[151],[152],[153],[154],[155]} A summary of the reported capital and operating costs for gasification facilities is presented in Table 7-3.

Table 7-3: Summary of Reported Capital and Operating Costs for Gasification Facilities (2009\$ CDN)

	Capital Costs (Annual Design Tonne)	Operational Costs
Lowest Reported Cost	\$134	\$37.22
Highest Reported Cost	\$1,410 (200,000 tpy capacity)	\$117.67
Median Reported Cost	\$803 +/- 42%	\$61.08 +/- 46%

¹⁵¹ MOSA, 2009. Summary Report on Estimated Costs to Develop and Operate new Regional Waste Disposal and Processing Facilities

¹⁵² NYC, 2006. Focused Verification and Validation of Advanced Solid Waste Management Conversion Technologies

¹⁵³ URS, 2005. Los Angeles County, Conversion Technology Evaluation Report

¹⁵⁴ MacViro, 2007. City of Ottawa REOI Report

¹⁵⁵ MacViro, 2007. County of Dufferin, RFP Process

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 7: Associated Costs and Energy Efficiency

The reported operating and capital costs are not based on those incurred by actual operating facilities or guaranteed via any procurement process. In most cases this information was provided by technology vendors through REOI or RFQ processes, in which the vendors were not required to guarantee a price. It is not clear that reported capital costs address all capital and construction cost elements. Nor is it clear that reported operating costs address all real costs associated with such facilities.

7.1.1.3 Plasma Arc Gasification

Capital costs were estimated based on four project estimates found during the literature review.^{[156],[157],[158]} A summary of the reported capital and operating costs for plasma arc gasification facilities is presented in Table 7-4.

Table 7-4: Summary of Reported Capital and Operating Costs for Plasma Arc Gasification Facilities (2009\$ CDN)

	Capital Costs (Annual Design Tonne)	Operational Costs
Lowest Reported Cost	\$859	\$87.37
Highest Reported Cost	\$2,027 (200,000 tpy capacity)	\$213.97
Median Reported Cost	\$1,225 +/- 44%	\$119.69 +/- 55%

The reported operating and capital costs are not based on those incurred by actual operating facilities or guaranteed via any procurement process. In most cases this information was provided by technology vendors through REOI or RFQ processes, in which the vendors were not required to guarantee a price. It is not clear that reported capital costs address all capital and construction cost elements. Nor is it clear that reported operating costs address all real costs associated with such facilities.

7.1.1.4 Pyrolysis

Cost range information for pyrolysis was made available through data gathering processes without any requirement for financial guarantees, and thus should be considered to be less reliable. Capital costs and operating costs were estimated based on six project estimates found during the literature review.^{[159],[160],[161]} A summary of the reported capital and operating costs for pyrolysis facilities is presented in Table 7-5.

¹⁵⁶ MOSA, 2009. Summary Report on Estimated Costs to Develop and Operate new Regional Waste Disposal and Processing Facilities

¹⁵⁷ NYC, 2006. Focused Verification and Validation of Advanced Solid Waste Management Conversion Technologies

¹⁵⁸ URS, 2005. Los Angeles County, Conversion Technology Evaluation Report

¹⁵⁹ MOSA, 2009. Summary Report on Estimated Costs to Develop and Operate new Regional Waste Disposal and Processing Facilities

¹⁶⁰ NYC, 2006. Focused Verification and Validation of Advanced Solid Waste Management Conversion Technologies

¹⁶¹ URS, 2005. Los Angeles County, Conversion Technology Evaluation Report

Table 7-5: Summary of Reported Capital and Operating Costs for Pyrolysis Facilities (2009\$ CDN)

	Capital Costs (Annual Design Tonne)	Operational Costs
Lowest Reported Cost	\$161	\$29.76
Highest Reported Cost	\$926 (200,000 tpy capacity)	\$104.58
Median Reported Cost	\$539 +/- 43%	\$50.87 +/- 52%

The reported operating and capital costs are not based on those incurred by actual operating facilities or guaranteed via any procurement process. In most cases this information was provided by technology vendors through REOI or RFQ processes, in which the vendors were not required to guarantee a price. It is not clear that reported capital costs address all capital and construction cost elements. Nor is it clear that reported operating costs address all real costs associated with such facilities. There is some indication that the capital cost per annual design tonne for such facilities is more likely over \$1,500/annual design tonne.

7.1.1.5 Summary of Capital and Operating Costs

Table 7-6 summarizes the information that has been obtained regarding capital and operating cost ranges for the four more common WTE technologies. Generally as the complexity of the technology increases so too does the capital and operating costs.

Table 7-6: Summary of Reported Capital and Operating Costs for Common WTE Facilities (2009\$ CDN)

Conventional Combustion	
Median Capital Cost	▪ \$775/annual design tonne +/- 50%
Median Operating Cost	▪ \$65/tonne +/- 30%
Gasification	
Median Capital Cost	▪ \$800/annual design tonne +/- 40%
Median Operating Cost	▪ \$60/tonne +/- 45%
Plasma Arc	
Median Capital Cost	▪ \$1,300/annual design tonne +/- 45%
Median Operating Cost	▪ \$120/tonne +/- 55%
Pyrolysis	
Median Capital Cost	▪ \$161 to \$926/annual design tonne – data is not as reliable
Median Operating Cost	▪ \$50 to \$105/annual design tonne – data is not as reliable

7.1.2 Cost Differentials between Technologies

As indicated above, generally the reported median capital and operating costs per design tonne reflect the increased complexity of the technologies and the sensitivity of the systems to factors such as the variable nature of MSW. The primary features that result in increased capital and operating costs for these technologies include:

- **Pre-processing of MSW:** generally gasification and pyrolysis processes require a more homogenous waste stream, necessitating a front-end pre-processing system to remove inert materials, blend the MSW and shred/process the combustible fraction of the MSW to a more consistent particle size. This increases both the capital and operating costs for such facilities.
- **Energy Recovery:** generally gasification and pyrolysis processes have a higher parasitic plant load, consuming more electrical energy and/or fossil fuels to operate the facilities. This increases operational costs and decreases the proportion of energy recovered for sale.
- **Emissions Control:** generally gasification and pyrolysis processes include both controls to improve the quality of the intermediate energy product (e.g., syngas) involving various treatment systems, and at least some portion of the APC systems that would normally be used for conventional combustion facilities to control flue gas emissions when the intermediate energy product is combusted.
- **Reliability of the Technology:** as noted in Section 2.1.3, the complexity of gasification and pyrolysis systems is associated with decreased reliability. Scheduled and unscheduled downtime for high temperature gasification is reported as approximately 20%, higher than that for conventional combustion. While actual information on reliability for plasma gasification and pyrolysis is not readily available, it would be anticipated to be similar or worse than high temperature gasification. Some information indicates for example that the refractory for plasma gasifiers requires very frequent replacement, increasing downtime and costs. As a result, generally higher capital replacement costs and operating costs would be incurred in comparison with conventional WTE approaches.

7.1.3 Costs Associated with Emissions Control

Semi-dry APC systems with SNCR generally are the lowest cost emissions control systems for conventional WTE facilities (mass burn). However, some technical limitations associated with the semi-dry system with SNCR may make it less acceptable in some jurisdictions. Limitations include possible exceedances of emission limits in short periods with high HCl or SO₂ concentrations, the potential to produce large amounts of residue that has to be handled, and odours associated with the ammonia in the dry flue gas treatment (FGT) residue.

A report by Ramboll completed in July 2007^[162] analyzed the costs associated with various emissions control technologies (see Table 7-7). The report came to the following conclusions:

- The base-case (semi-dry FGT) has the lowest capital costs.

¹⁶² Ramboll, 2007. The Regions of Durham and York EfW Facility, Comparison of Flue Gas Treatment Systems.

- The wet FGT system with higher capital cost has the lowest operational costs, partly due to high efficiency of the used chemicals and partly due to the lack of dry FGT residues.
- The capital cost of the SCR process is around eight times more expensive than SNCR.
- The SCR uses around 30% less ammonia when reducing the NO_x content just below the emission limit, but the operational costs of SCR is nevertheless higher than SCNR as high pressure steam must be used to heat the flue gas an additional 25°C and spent catalyst must be disposed and replaced.

Table 7-7: Operational and Capital Costs for Different Emissions Control Systems

	Type of FGT System		Yearly Operational Costs (in 1,000 CAD 2007\$)		Capital Costs (in 1,000 CAD 2007\$)		Overall Costs (in 1,000 CAD 2007\$)	
	Acid Gas Treatment	De-NO _x Process	Acid Gas Treatment	De-NO _x Process	Acid Gas Treatment	De-NO _x Process	Total Cost Over 20 Years	Difference from Base Case
Base Case	Semi-dry	SNCR	2,516	90	11,000	1,000	56,928	–
S1	Semi-dry	SNCR + Stripper	2,156	98	11,000	2,200	58,281	1,353
S2	Semi-dry	SCR	2,156	180	11,000	7,000	64,728	7,800
S3	Wet	SNCR	1,887	90	21,000	2,200	61,546	4,618
S4	Wet	SNCR + Stripper	1,887	98	21,000	2,200	62,899	5,971
S5	Wet	SCR	1,887	180	21,000	7,000	69,346	12,418
S6	Semi-Wet	SNCR	2,198	90	14,000	1,000	60,763	3,835
S7	Semi-wet	SNCR + Stripper	2,198	98	14,000	2,200	62,116	5,188
S8	Semi-wet	SCR	2,198	180	14,000	7,000	68,563	11,635

As indicated in Table 7-4, the operational costs over 20 years are lower for wet emissions control systems, however there are significantly higher capital costs associated with this type of system.

7.2 Thermal Efficiency and Energy Recovery

Each of the WTE technologies discussed thus far has relative advantages and disadvantages associated with their operation.

This section of the report will discuss the thermal efficiency and energy recovery typical of mass burn incineration facilities (conventional combustion) and gasification facilities. There is insufficient information currently available to discuss the efficiency and energy recovery rates associated with pyrolysis and plasma arc gasification facilities.

7.2.1 Energy Recovery from Mass Burn Facilities

The combustion of waste is a heat generating process. Most of the energy produced during combustion is transferred to the flue gases which are cooled as they pass through the plant allowing for the capture of energy via a heat recovery boiler (which transfers the heat energy to water causing the production of steam or hot water).

Energy produced by such facilities can be used in the:

- Production and supply of heat (as steam or hot water)
- Production and supply of electricity (i.e., via a steam turbine), or,
- Production of heat and electricity (i.e., combined heat and power, CHP).

The energy produced can be used on-site and/or off-site. Heat and steam are commonly used for industrial processes or district heating systems while electricity is often supplied directly to an energy grid or used within the system.

Several factors influence the energy efficiency associated with mass burn incineration facilities.

These factors include:

- Characteristics of the waste being treated (chemical and physical characteristics – MJ/kg). Typical values of waste net calorific values are between 8 and 12.6 MJ/kg
- Plant design (increased steam parameters – boilers and heat transfer)
- Energy sale possibilities (heat and electricity or just electricity), and
- Local conditions (e.g., meteorological conditions – if the plant is located in a warm environment the use of district heating would not be practical).

The highest levels of waste energy utilization are normally obtained when the heat recovered can be supplied continuously as district heat (or process steam) or in combination with electricity generation. The use of district heat (or process steam), however, is highly dependent on the availability of a user for the energy (as well as local meteorological conditions).

The production of electricity alone is a common method that WTE facilities use to recover energy from the incineration process. Electricity only operations are less efficient than those that recover and use district heat (or process steam) but are less dependent on local conditions and therefore are widely employed.

Modern mass burn facilities that produce only electricity regularly recover and sell electricity in the range of 550 kWh/tonne of waste. Facilities that recover both heat and electricity can generate considerably more energy per tonne of waste treated. The WTE facility located in Brescia, Italy produces/markets 650 kWh and 500 kWh of electricity and heat respectively per tonne of waste treated. The WTE facility located in Malmo, Sweden (a much colder climate therefore increasing the beneficial uses of district heating) produces/markets 280 kWh and 2,580 kWh of electricity and heat respectively per tonne of waste treated. The Metro Vancouver WTE facility produces about 470 kWh

of electricity and 760 kWh of steam per tonne of waste (it should be noted that the Metro Vancouver facility was built in 1988, and higher efficiencies are now possible with BAT).^[163]

The following table (Table 7-8) provides ranges of potential efficiencies at incineration plants in a variety of situations. The actual figures at an individual plant will be site-specific. The purpose of the table, therefore, is to provide a means to compare what might be achievable under favourable circumstances. It should be noted that the reported efficiencies do not take into account boiler efficiencies (which exhibit typical losses in the order of 20%).^[164]

It is important to realize that direct comparison of WTE facilities with other power stations should be avoided. This is due to the fact that the conversion of steam into electricity at WTE facilities is limited by the composition of the waste (e.g., high chlorine content may cause corrosion in the boiler or economizer) and that when flue gas in is the range of approximately 250 – 400°C it cannot generally be used for generation of steam as this is considered to be the range in which de novo synthesis of dioxins/furans take place,^[165] discussed earlier in Section 3.1.1.

Table 7-8: Energy Potential Conversion Efficiencies for Different Types of Waste Incineration Plants^[166]

Plant Type	Reported Potential Thermal Efficiency %
Electricity Generation Only	17 – 30
Combined Heat and Power (CHP)	70 – 85
Heating Stations with Sales of Steam and/or Hot Water	80 – 90
Steam Sales to Large Chemical Plants	90 – 100
CHP and Heating Plants with Condensation of Humidity in Flue gas	85 – 95
CHP and Heating Plants with Condensation and Heat Pumps	90 – 100

NOTE:

The figures quoted in the above table are derived from addition of MWh of heat and MWh of electricity produced, divided by the energy output from the boiler. No detailed account is taken of other important factors such as: process energy demand (support fuels, electrical inputs) or displacement of electricity and heat generation.

A number of factors can be considered when attempting to increase the thermal efficiency of the waste incineration process. These include:

- Waste pre-treatment (homogenization and/or separation of non-suitable materials)
- Design of boilers for increased heat transfer

¹⁶³ AECOM. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

¹⁶⁴ European Commission. 2006. Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration

¹⁶⁵ TWG. 2001. Draft of a German Report with basic information for a BREF-Documents “Waste Incineration”

¹⁶⁶ European Commission. 2006. Integrated Pollution Prevention and Control Reference Document on the Best Available Techniques for Waste Incineration

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 7: Associated Costs and Energy Efficiency

- Combustion air pre-heating (can have a positive influence on overall energy efficiency in the case of electricity production)
- Use of water cooled grates
- Flue gas condensation
- Use of heat pumps
- Flue gas re-circulation
- Steam-water cycle improvements.

7.2.2 Energy Recovery from Gasification Facilities

All existing gasification technologies examined, have lower energy recovery efficiencies than those currently being achieved by modern mass burn incinerators.^[167] This is due to the fact that a mass burn process generally results in more complete combustion of the fuel compared to gasification and/or as the support fuel/electrical inputs for gasification tend to be higher.

The gasification process results in the production of syngas which can be used similarly to natural gas. Syngas can be used to fuel a conventional boiler (similar to a mass burn system) to produce steam and drive a turbine which results in the production of electricity, but it can also be used in reciprocating engines to produce electricity and heat, combined cycle gas turbine plants to produce electricity and heat, or fuel cells, or it can be converted into ethanol.

The efficiencies of the gasification process depend on how the syngas is used. When used to produce electricity using a steam boiler and turbine, efficiencies are in the range of 10% to 20%. When burned in reciprocating engines, efficiencies increase slightly to in the range of 13% to 28%, and in combined cycle gas turbines, they can be as high as 30%. It should be noted, that there are no known commercial scale applications of combined cycle gas turbines using syngas produced from MSW, therefore this number should be considered theoretical in nature. When used for district heating (CHP) over 90% efficiencies can be achieved.^[168]

Interstate Waste Technologies (who market the Thermoselect gasification technology in North America) report that the Thermoselect technology can produce 641 kWh of net electricity per tonne of waste treated.^[169] When the Thermoselect technology is combined with reciprocating engines, overall net efficiency is approximately 13% (exported power divided by thermal input).^[170]

7.3 European Union Energy Efficiency Equation Experience

In December 2008, the European Union's (EU) Waste Framework Directive (2008/98/EC) came into force. The Waste Framework Directive (WFD) provides an umbrella for all other European waste

¹⁶⁷ Fichtner Consulting Engineers Limited. 2004. The Viability of Advanced Thermal Treatment of MSW in the UK

¹⁶⁸ AECOM. 2009. Management of Municipal Solid Waste in Metro Vancouver – A Comparative Analysis of Options for Management of Waste After Recycling

¹⁶⁹ Alternative Resources, Inc. 2008. Evaluation of Municipal Solid Waste Conversion Technologies

¹⁷⁰ Fichtner Consulting Engineers Limited. 2004. The Viability of Advanced Thermal Treatment of MSW in the UK

legislation. The WFD includes an energy efficiency equation which will be adopted into legislation in the individual member states by December 31, 2010. The WFD lays down measures to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use.

The WFD presents a five-step hierarchy of waste management options which must be applied by Member States when developing their national waste policies. The waste hierarchy given is as follows:

1. Waste prevention
2. Re-use
3. Recycling
4. Recovery (including energy recovery)
5. Safe landfill disposal, as a last resort.

The WFD considers energy-efficient waste incineration a recovery operation, provided that it complies with certain energy-efficiency criteria.^[171] In order to determine whether or not a WTE facility is deemed a recovery operation, the WFD presents an energy efficiency formula which calculates a facility's energy efficiency.

The energy efficiency formula is as follows:^[172]

$$\text{Energy efficiency} = (Ep - (Ef + Ei)) / (0.97 \times (Ew + Ef))$$

- *Ep* means annual energy produced as heat or electricity (GJ/year). It is calculated by applying an equivalence factor of 1MWh electricity produced being equivalent to 2.6 MWh of electricity imported from other sources onto the grid and by applying an equivalency factor of 1MWh of fuel replaced by heat produced being equivalent to 1.1 MW of imported fuel.
- *Ef* means annual energy input to the system from fuels contributing to the production of steam (GJ/year)
- *Ew* means annual energy contained in the treated waste calculated using the net calorific value of the waste (GJ/year)
- *Ei* means annual energy imported excluding *Ew* and *Ef* (GJ/year)
- 0.97 is a factor accounting for energy losses due to bottom ash and radiation.

Using this formula, an incineration facility is considered a recovery operation if it reaches an energy efficiency of 0.60 for installations in operation and permitted before January 1, 2009 and 0.65 for

¹⁷¹ European Parliament (November 11, 2008), *The Legislative Observatory Final Legislative Act*, Retrieved February 19, 2010, from <http://www.europarl.europa.eu/oeil/file.jsp?id=5303132>

¹⁷² Official Journal of the European Union (November 22, 2008), Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste and Repealing Certain Directives, Retrieved February 19, 2010, from http://www.wastexchange.co.uk/documenti/europeanorm/DIR2008_98_EC.pdf

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 7: Associated Costs and Energy Efficiency

installations permitted after December 31, 2008.^[173] Those WTE facilities that reach these criteria are considered R1 recovery operations.

The drivers behind the WFD and the R1 formula were many and to a certain degree contradicting, some are mentioned below:

- In the EU, when waste is co-incinerated in cement kilns, the process is defined as recovery, whereas incineration of MSW in dedicated WTE facilities is defined as disposal. The WTE industry found this definition unreasonable.
- Recovery of energy from waste is an important component in a European waste management business model. Energy is a precious resource and the WTE industry felt it should be credited this benefit. WTE also allows for material recovery, however material recovery is not accounted for by the energy efficiency equation.
- According to the EU transport regulation, trans-boundary transport of waste for recovery is allowed without any particular control, whereas trans-boundary transport of waste for disposal is subject to multiple restrictions and controls.

As a first step the produced energy is determined by considering produced electricity and thermal energy for commercial use. Two equivalency factors are applied: 2.6 as a factor if electricity is produced in lieu of electricity imported from other energy generating sources onto the grid and 1.1 if thermal energy is produced in lieu of imported fuel. The factor takes into account the efficiency of the energy production which is replaced by WTE production. In a second step the energy input from fuels and sources other than waste is subtracted ("Energy from fuels", "Other imported energy"). Energy input from fuels (e.g., gas firing for start-up operations; electricity supply from the grid) is deducted. The remaining figure is the energy produced only by waste input. In a third step the energy produced only by the waste input is divided by the energy content of the waste (the potential of energy contained in the waste, calculated from the lower calorific value) plus the energy input from fuels. Note: generally the energy content of the waste is determined through published values for specific material streams and/or fuel testing, but there are no specific requirements for fuels/material testing that must be met in application of the energy efficiency formula. In addition the denominator is multiplied by 0.97. This factor accounts for energy losses via bottom ash and radiation.

If a WTE facility does not meet the R1 criteria it is deemed a disposal facility and falls to the lowest level of the hierarchy.^[174]

As indicated in the Figure 7-3 below, WTE facilities generating a mix of both heat and power generally easily fulfill the efficiency formula having an R1 of between 0.6 and 0.8, and are defined as recovery. WTE facilities with optimized power production of over 700 kWh/tonne of waste will as well be able to fulfill the requirement for recovery whereas several facilities, especially older ones, might not be able to fulfill the requirement and will not succeed in being defined as recovery.

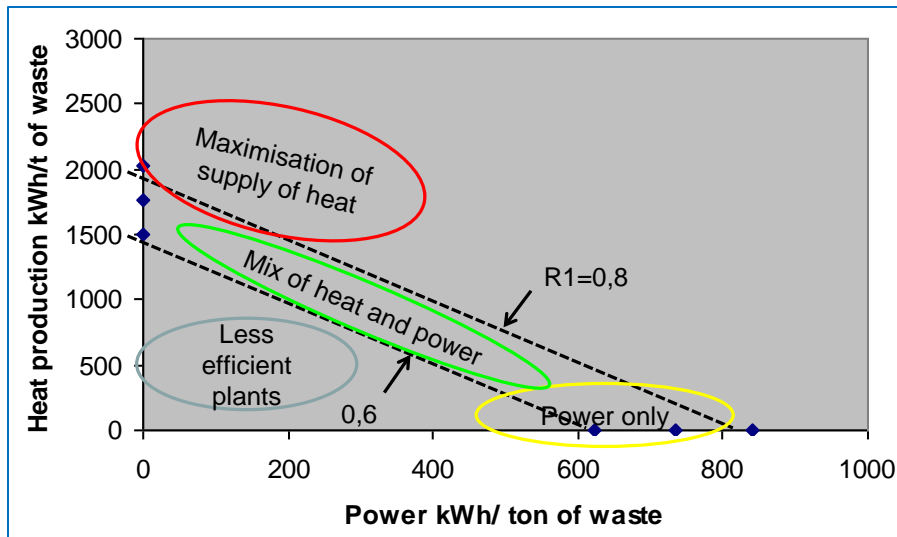
¹⁷³ The formula only applies to incineration facilities dedicated to the processing of municipal solid waste (reference 139)

¹⁷⁴ Institut für Ökologie und Politik GmbH (June 2006), *The Energy Efficiency Formula of Annex II of the Waste Framework Directive, A Critical Review*. Retrieved February 19, 2010, from http://www.eeb.org/activities/waste/waste_strategy/20060630-Okopol-Brief-on-MSWI-efficiency-formula-v5-final.pdf

It should be noted that the equation is not entirely clear and may be interpreted differently from one country to another. In addition, the impact of a facility's internal energy consumption is often discussed (e.g., if pre-treatment is required for the process it should then be calculated independently if pre-treatment is carried out at another location). This is of relevance for some mass burn facilities but even more so for fluidized bed incinerators and for the emerging technologies where the internal consumption of energy for waste pre-treatment is relatively high.

Figure 7-3: Relationship of Heat to Power Production for WTE Facilities

NOTE:



The dashed lines above represent an R1 of 0.6 and 0.8 respectively.

The EU Commission is in the process of further defining the use of the formula, as practical use of the formula showed that a transparent and harmonized way of calculating energy efficiency was necessary among the member states. The commission has engaged consultants, CEWEP, and other interest groups to evaluate and further define the use and the interpretation of the formula.

The Waste Framework Directive has to be implemented in all member states no later than December 31, 2010. For this purpose, the EU Commission will by the end of October 2010 publish European guidance for the use of the R1 energy efficiency formula for incineration facilities dedicated to the processing of MSW. The draft guidance is defining among others:

- The scope of the Energy Efficiency Formula
- The system boundaries
- The qualification procedure and monitoring of compliance.

Some countries in the EU have already adopted and implemented use of the formula. For example, the Netherlands has implemented the formula but takes the internal energy consumption of the facility into account. Five plants, representing approximately 70% of the country's capacity, are

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 7: Associated Costs and Energy Efficiency

defined as recovery whereas the remaining facilities did not succeed in fulfilling the required efficiency and are therefore defined as waste disposal.

In Denmark the WFD has been adopted but without the formula. All WTE facilities in Denmark generate both heat and power and have an energy efficiency value of greater than 0.65. All plants will easily be defined as recovery according to the definition in the WFD. It is possible this value may be increased by government to drive continuous improvement in energy efficiency. The definition of recovery versus disposal and use of the equation is further complicated by the potential future imports of MSW, which are currently prohibited, into Denmark.

In Italy it is most likely that the input energy to the WTE facilities will be taken into account. Only energy that is actually sold (as heat and/or power) is allowed to be considered. The application of the formula is complicated by seasonal variations in consumption of energy where district heating is applied. Further, there is uncertainty in how to address facility consumptive use of power in the calculation. Principally this means that a WTE facility that is considered a recovery facility one year may be considered as a disposal facility in subsequent years should some or all of the energy not be sold.

In France a waste incineration tax is charged to plants defined as disposal facilities but not to plants determined to meet the recovery criteria. France recently started using the equation but is awaiting the published guidance later in 2010 for consistent application.

In the UK and in Scotland new WTE facilities have to prove they are able to achieve energy efficiency above 0.65 in order to obtain an operating permit. Similar to France, the UK and Scotland recently started using the formula, pending release of the EU guidance on application.

In summary, there is inconsistent application of the energy equation in the EU. The situation should be clarified somewhat with the release of additional guidance by the EU in the fall of 2010.

7.4 WTE Energy Recovery and Revenue Streams in BC

Direct revenue streams for WTE facilities include those from the sale of energy (including any combination of district heat generation and generation of electricity), from the sale of recovered materials (e.g., metals) and from tipping fees.

For every tonne of MSW consumed in a WTE facility, it is typically possible to generate up to 2 MWh of heat energy (as hot water or steam) and in the order of 0.5 to 0.8 MWh of electrical energy or any combination thereof depending on the design of the plant. The total amount of energy generated and marketed depends on the total available energy associated with the mass of MSW processed, and the ability to find a market for the energy.

Table 7-9 provides an overview of the potential energy generation and energy sales for a 100,000 tpy conventional (mass burn) WTE developed in a BC market, combusting post-diversion residual waste, if the sale of heat energy were to be limited by local market conditions. The composition of the post-diversion residual material assumes that a source separated organics diversion program is in place, diverting in the order of 60% or more of the 'wet' food materials from the waste stream.

Table 7-9: Potential Energy Generation and Energy Sales for a 100,000 tpy Conventional WTE Facility in a BC Market

Electricity Generation	Based on post source separated organics (SSO) waste composition and characteristics: <ul style="list-style-type: none"> ▪ Average Net Energy Production: 770 kWh/tonne ▪ Waste Energy Content: 13 MJ/kg ▪ Plant Heat Rate: 16.9 MJ/kWh
Combined Heat and Power (CHP)	CHP contingent upon development of proximate users of heat energy, that could be limited given local conditions
Auxiliary Fuel	Requires Natural Gas, for start up and temperature control
Bottom Ash Handling	Bottom ash quenched, quench water recycled Bottom ash screened and magnetically separated to remove ferrous and non-ferrous metals with 55% recovery rate
Power Island	One single casing steam turbine generator, mechanical draft cooling tower

Revenue streams for such a WTE Plant could generally include the following:

- Electricity Sales
- Sales of Ferrous and Non-Ferrous Metals, recovered from the bottom ash
- Tipping Fee revenue from commercializing plant capacity.

The value of these revenue streams is entirely contingent upon the market for the commodities noted, and in some cases it is difficult to determine with any degree of relative certainty at this time.

With regard to electricity sales, market prices are contingent upon the jurisdiction. For example, market prices for energy from waste have recently been established in Ontario of 8.5 cents per kWh. At that rate, electricity sales from a 100,000 tpy WTE plant could be in the order of \$6.5 million annually. However, it is likely that lower energy prices would prevail in BC based on the prevalence of renewable energy sources in the market. For BC residential customers, a two-step Conservation Rate is applied on an interim basis.^[175] As of April 1, 2010, the current cost of electricity in BC is 6.27 (Step 1) and 8.78 (Step 2) cents per kWh.

Should a proximate market for heat be developed (e.g., development of greenhouses), the potential for heat recovery for a 100,000 tpy conceptual WTE plant would vary between 46 million kWh (conservative based on high pressure steam, electricity production reduced to 88%) and 136 million kWh (hot water recovery based on BAT EU practice, electricity production reduced to 80% with 2 units of heat produced for each unit of electricity). For heating of greenhouses, the best option would be recovery of hot water that could be supplied and used in radiant heating systems. Heat recovery would decrease net electricity production and revenues, between 12.5 and 20%. The market would be contingent upon the energy requirements for greenhouses which vary, based on design (materials, construction method) and climate. Assuming that the heat sold replaces that which would

¹⁷⁵ BC Hydro. April 1, 2010, Electricity Rates. Website: http://www.bchydro.com/youraccount/content/electricity_rates.jsp.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 7: Associated Costs and Energy Efficiency

be otherwise generated by burning natural gas, and considering potential energy markets, the heat could be sold at approximately \$0.04/kWh. For a 100,000 tpy facility, annual revenues from the sale of heat could vary between \$1.8 and \$5.4 million.

Revenues earned from the sale of recovered materials, could include revenues from the sale of recovered metals (ferrous and non-ferrous), recovered reagents from the APC train (e.g., gypsum) and recovery of aggregate from bottom ash. Considering the current state of the industry in North America, it is reasonable to assume markets for recovered metals, but not necessarily for any other recovered materials. In regards to revenues from the sale of ferrous and non-ferrous metals recovered from the bottom ash of the WTE plant (assuming a 100,000 tpy capacity), approximately 9,000 tpy of metals could potentially be recovered (pending confirmation of the characteristics of the MSW stream that would be managed at the plant). Based on current North American metals markets, which are somewhat depressed compared to previous years, a conservative estimate for this material stream would be \$200/tonne or approximately \$1.8 million annually.

It is difficult to determine if or how much revenue would be generated through tipping fees for a WTE plant in BC. Current Metro Vancouver tipping fees at waste disposal sites are in the order of 82 to 86 \$/tonne.^[176] For a new WTE facility the ownership model (public or private) is anticipated to have a role in setting tipping rates.

As discussed above, the overall energy efficiency (and revenues from sale of energy) are potentially limited by the available markets for sale of heat energy, and other limitations including electricity pricing.

The Environmental Protection Division has an operational policy that addresses the review of SWMPs which include MSW as a feedstock for WTE facilities. This policy states that the ministry prefers WTE facilities that incorporate resource recovery (as part of a waste management hierarchy) and expects that energy recovery facilities would meet at least 60% efficiency based on a calculation similar to the EU energy efficiency equation. However, any new WTE facilities in BC may not be able to achieve an energy efficiency of 60% without further development of infrastructure such as district heating that would facilitate the use of heat generated by a WTE facility, recognizing that a high efficiency is difficult to reach through the production of electricity alone. The lessons learned in Europe as EU member states implement the energy efficiency equation during the last half of 2010 may provide guidance to the ministry about interpretation of the equation and how it may be further applied in a BC context.

¹⁷⁶ Metro Vancouver Disposal Facilities. Website:
<http://www.metrovancouver.org/services/solidwaste/disposal/Pages/disposalfacilities.aspx>

7.5 Summary – BAT for Energy Recovery

The following list outlines the BAT for energy recovery from WTE facilities^{[177] [178]}:

- Overall optimization of energy efficiency and energy recovery taking into account techno-economic feasibility and the availability of users for the energy to be recovered.
- Reduction of energy loss via the flue gases (i.e., reduce flue gas flow to recover more heat energy).
- The use of a boiler to transfer energy with a thermal conversion efficiency of at least 80%.
- Securing where possible, long-term heat/steam supply contracts to large heat/steam users to maximize the heat/steam usage.
- Locate in an area where heat and/or steam use can be maximized through any combination of:
 - Electricity generation with heat or steam supply (combined heat and power – CHP)
 - District heating
 - Process steam to industrial or other facilities
 - Heat/steam supply for use in cooling/air conditioning systems (through the use of absorption chillers, which use steam or hot water to drive a phase change in a medium to create a cooling effect).
- Where electricity is generated, optimization of steam parameters including consideration of the use of higher steam parameters to increase electricity generation.
- The selection of a turbine suited to the electricity and heat supply regime and high electrical efficiency.
- Where electricity generation is a priority over heat supply, the minimization of condenser pressure.
- General minimization of overall facility energy demand including consideration of the following:
 - Selecting techniques with lower energy demand over those with higher energy demand
 - Ordering APC components to avoid the requirement for flue gas reheating
 - If flue gas reheating is necessary, the use of heat exchanger systems to minimize energy demand.
- The location of a new facility so that the use of CHP and/or heat and/or steam can be maximized so as to generally exceed an overall total energy export level of 1.9 MWh/tonne of MSW based on an average net calorific value (NCV) of 2.9 MWh/tonne.
- Reduce the average installation electrical demand to be generally below 0.15 MWh/tonne of MSW processed based on an average NCV of 2.9 MWh/tonne.

¹⁷⁷ European Commission. 2006. Integrated Pollution Prevention and Control: Reference Document on the Best Available Techniques for Waste Incineration.

¹⁷⁸ Federal Environment Agency – Austria. 2002. State of the Art for Waste Incineration Plants.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 7: Associated Costs and Energy Efficiency

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8 EMISSION MONITORING SYSTEMS

In order to determine compliance with facility emission permit limits, operators must undertake emission monitoring and report the results to regulatory authorities. Point source emissions monitoring is conducted either on continuous basis or periodic (non-continuous) basis.

Continuous monitoring measures parameters of concern using stationary monitoring equipment permanently installed at various locations within combustion, APC or discharge flue of the facility. Continuous monitors are typically used for operational control and occasionally for compliance measurements. The results from the continuous monitor are representative of the location on the system where they are installed, and therefore may not always represent the concentration in the discharge.

Periodic emission monitoring, also called stack sampling, is usually performed on a prescribed frequency, with the period specified (usually quarterly, annually or semi-annually) by the facility SWMP or permit in the case of WTE, and is therefore non-continuous. Periodic stack sampling is performed by a sampling crew of at least two people that extract a discrete sample from the stack for the facility. This method of determining discharge quality consists of obtaining samples of the emission stream according to approved protocols. The duration of the stack test is determined by the size of the stack, the number of prescribed sample points within the stack, the degree of difficulty in maintaining standard operating conditions during the test, and the number of replicate tests required by the test procedure.

Continuous emissions and periodic stack testing monitoring methods are discussed in additional detail below.

8.1 Continuous Emissions Monitoring Systems (CEMS)

Modern WTE monitoring systems ensure that air emissions resulting from plant operation fall within specified limits. Projects initiated within Canada are required to use Environment Canada or US Environmental Protection Agency (EPA) protocols and performance specifications listed in Appendix 7.1 of the BC *Stationary Air Emissions Testing* manual.^[179] New stationary continuous source testing methods can be approved if they meet the requirements of US EPA Method Validation Protocol Method 301.^[180] In conventional combustion facilities, Continuous Emissions Monitors Systems (CEMS) are installed to monitor the internal operations of the facility components to ensure the emissions leaving the facility are at appropriate levels.

The types of parameters that CEMS usually monitor and record include:

- The baghouse outlet for opacity, moisture, CO, TOC, O₂, NO_x, SO₂, HCl and HF. Opacity measurements would be used as the filter bag leak detection system

¹⁷⁹ British Columbia Field Sampling Manual Part B: Air and Air Emissions Testing. Stationary Air Emissions Testing. 2003.

¹⁸⁰ US EPA. CFR Promulgated Test Methods. Method 301 – Method Validation Protocol. Field Validation of Pollutant Measurement Methods from Various Waste Media.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 8: Emission Monitoring Systems

- The economizer outlet for O₂, SO₂ and CO
- Flue gas temperatures at the inlet of the boiler convection section and at the baghouse inlet
- The temperature and pressure of the feedwater and steam for each boiler
- The mass flow rate of steam at each boiler.

Often a long-term continuous sampling device can be installed to sample for dioxin/furan emissions over a fixed period of time, commonly two weeks or one month.^[181] In some countries, especially France and Belgium, intensive public concerns regarding dioxin emissions arose in many communities around 10 years ago as old WTE facilities were suspect for uncontrolled dioxin emissions. To prove that the WTE facilities were able to control dioxin emissions not only when the stack sampling was undertaken but on a continuous basis, initiatives were taken to develop and install continuous dioxin sampling devices. The continuous sampling equipment is in principle identical to the periodic sampling equipment but actually takes a sample from the stack over a period of 14 days or more. The probe is then sent for laboratory analysis. While the samples are taken on an on-going basis, this is not true continuous monitoring as the result is representative of an average concentration over the sampling period. Dioxin sampling is not regulated in the EU and thus there is no emission limit that is applicable for the long term sampling. However, some WTE plants mainly in Belgium and France, have voluntarily installed these continuous dioxin sampling devices.

In regards to particulate emission monitoring, progress has been made in regards to CEMS systems suitable for monitoring particulate. The use of CEMS to determine the concentration of particulate matter in the emission stream has yet to be widely adopted. Several different types of PM CEMS technologies (e.g., light scattering, Beta attenuation, etc.) are available, each with certain site-specific advantages. The USEPA recommends that proponents select and install a PM CEMS that is appropriate for the flue gas conditions at the source. Opacity is often used as a surrogate, but attempts to directly correlate opacity to PM emissions have not been reliable.^[182] The more commonly applied method of determining particulate matter concentrations utilizes the periodic stack sampling method EPA Method 5, as discussed in the next section.

Continuous particulate mass monitoring is required by the USEPA as part of the hazardous waste combustion MACT. The USEPA promulgated Performance Specification 11 (PS-11)^[183] in January 2004, in order to establish the initial installation and performance procedures that are required for evaluating the acceptability of a particulate matter (PM) continuous emission monitoring system. PS-11 outlines the procedures and acceptance criteria for installation, operation, calculations and reporting of data generated during the site-specific correlation of the PM CEMS response against manual gravimetric Reference Method measurements. Procedures for evaluating the ongoing performance of a PM CEMS are provided in Procedure 2 of Appendix F – Quality Assurance Requirements for Particulate Matter Continuous Emission Monitoring Systems Used at Stationary Sources.

¹⁸¹ Durham/York Residual Waste Study Environmental Assessment, November 27, 2009, Stantec Consulting Ltd

¹⁸² Status of Particulate Matter Continuous Emission Monitoring Systems, EPRI, Palo Alto, CA: 2001. 1004029.

¹⁸³ USEPA APPENDIX B OF PART 60 – PERFORMANCE SPECIFICATIONS PERFORMANCE SPECIFICATION 11 - Specifications and Test Procedures for Particulate Matter Continuous Emission Monitoring Systems at Stationary Sources, January 12, 2004.

Up until recently, although guidance was provided regarding PM CEMS by the USEPA it has not yet been widely used in the USA as a suitable monitoring approach for the purpose of demonstrating regulatory compliance because of measurement accuracy and repeatability issues. However, this has recently changed. The US EPA recently issued for public comment, 40 CFR Part 60 (new standards for incineration units), which includes requirements for example for new waste energy recovery units which would require units that have a design capacity greater than 250 MMBtu/hr, to include monitoring of PM emissions using a PM CEMS.^[184] For other incineration facilities, the use of PM CEMS would be optional as an alternative to periodic sampling.

The proposed new requirements for incineration units discuss the methods used to develop proposed new emissions limits, and discuss the use of averaging periods as they relate to CEMS or stack tests. For example, the proposed PM emission limits are based on data from infrequent (normally annual) stack tests and compliance would generally be demonstrated by stack tests. The use of PM CEMS for measurement and enforcement of the same emission limits must be carefully considered in relation to an appropriate averaging period for data reduction. Because historical PM CEMS data are unavailable for the solid waste incineration sector, EPA concluded that the use of a 24-hour block average was appropriate to address potential changes in PM emissions that cannot be accounted for with short term stack test data. The 24-hour block average would be calculated following procedures in EPA Method 19 of Appendix A-7 of 40 CFR part 60.^[185]

CEMS requirements vary between jurisdictions, with some common parameters being measured via CEMS but not all; and few jurisdictions have reviewed and assessed the potential requirement for mandatory CEMS for particulate. The following table presents an overview of the continuous emissions requirements as outlined in the current BC MSWI guidelines, Ontario Guideline A-7 (revised October 2010) and the EU Waste Incineration Directive.^[186]

Table 8-1: Continuous Emissions Monitoring in BC, Ontario and EU

Pollutant	BC 1991 MSWI Emission Criteria	Ontario Guideline A-7 (Parameters Considered for Continuous Monitoring)	EU Waste Incineration Directive
Temperature	X	X	X
Organic matter		X	
Carbon monoxide	X	X	X
Residual oxygen		X	X
Carbon dioxide		X	
Volumetric flow rate of the flue gas		X	
Hydrogen chloride	X	X	X
Sulphur dioxide		X	X

¹⁸⁴ ENVIRONMENTAL PROTECTION AGENCY, 40 CFR Part 60 EPA-HQ-OAR-2003-0119; FRL- RIN 2060-AO12 Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Commercial and Industrial Solid Waste Incineration Units, April 2010.

¹⁸⁵ Ibid.

¹⁸⁶ Ontario Ministry of the Environment. Guideline A-7: Air Pollution Control, Design and Operation Guidelines for Municipal Waste Thermal Treatment Facilities, October 2010.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 8: Emission Monitoring Systems

Pollutant	BC 1991 MSWI Emission Criteria	Ontario Guideline A-7 (Parameters Considered for Continuous Monitoring)	EU Waste Incineration Directive
Hydrogen fluoride		X	X
Nitrogen oxides		X	X
Opacity	X	X	
TOC			X
Total Dust/Particulate Matter		X	X

The Waste Incineration Directive also requires that O₂ concentration, pressure, temperature, and water vapour content of exhaust gas be continuously monitored. Periodic, instead of continuous, monitoring of HCl, HF, and SO₂ may be authorized if the operator can prove that the emissions of these pollutants can under no circumstance be higher than the prescribed emission limit values. The WID also requires at least two measurements per year of heavy metals, dioxins and furans (one measurement at least every three months for the first 12 months of operation). Further, if the operator can demonstrate that the emissions of heavy metals and dioxins/furans are always below 50% of the emission limit values, the operator only needs to test for heavy metals once every two years (instead of twice a year) and for dioxins/furans once a year (instead of twice a year). Some EU member nations impose additional requirements. For example, Germany requires that Hg be monitored continuously.

8.2 Periodic Emission Monitoring

Currently in BC, to determine if a discharge is in compliance with permit requirements, periodic non-continuous sampling may be required on a quarterly, semi-annually or annual basis. Field monitoring conducted for each survey must be conducted by certified stack test technicians as required by the BC *Stationary Air Emissions Testing* manual.^[187] This method of testing is also commonly called 'manual stack testing' and involves obtaining a representative sample of the emission from the flue over a period of time at a prescribed number of sample locations. Stack testing is conducted according to strict, approved protocols published in the BC Field Sampling Manual, the BC Air Analytical Manual, the US Environmental Protection Agency methods, or by other approved sampling and analytical methods.^{[188] [189]} The USEPA methods generally represent the approved period sampling methodologies for stationary sources, in many cases for specific industry sectors or specific emission sources.

The duration of a periodic stack test is linked with the diameter of the stack and therefore the number of sample locations on each traverse, the variability of the emission rate relative to standard

¹⁸⁷ British Columbia. Field Sampling Manual for Continuous Monitoring and the Collection of Air, Air-Emission, Water, Wastewater, Soil, Sediment, and Biological Samples. 2003

¹⁸⁸ US Environmental Protection Agency 40 CFR Parts 60, 61 and 63

¹⁸⁹ British Columbia Environmental Laboratory Manual for the Analysis of Water, Wastewater, Sediment, Biological Materials and Discrete Ambient Air Samples. 2007

operating conditions during the test, and the number of replicate tests that are required to meet permit requirements. Typically, the test methodology will extract a sample from the discharge stream and collect the parameters of interest on a filter paper (for particulates) or in a reagent or resin (such as XAD-2 resin for organic constituents) for subsequent chemical analysis. Results are initially produced on a mass basis and are then converted to concentration values on the basis of the volumetric discharge rate. Therefore, the test results are representative of an average concentration for the duration of the sampling period. In BC a valid manual stack survey consists of three individual sample runs, and the result is then reported as the average of the triplicate tests. The discharge of particulate, speciated particulate, trace metals, speciated organics and other specific parameters are typically monitored using manual stack testing techniques.

It is important to note that the results produced by this testing method are representative of the operational performance and actual emissions during the duration of the test run.

Emission criteria must consider the methods available to determine compliance and base the limit on the period over which the sample is obtained.

8.3 Commonly Accepted Emission Monitoring Methods

Periodic stack testing requires the application of approved testing methods. Sampling methods have been developed for most all contaminants that may be encountered. The approved methods specify the locations and conditions under which testing can be considered representative of the emissions. The approved methods also define the reagents to be used in the sampling equipment and define how to handle the samples. The US EPA is one of the primary approving bodies for testing methods and their approved methods are adopted in Canada and in some EU countries. The province has in general, adopted the US EPA methods for application in BC. Continuous monitoring by CEMS also has prescribed methods for locating the monitors and for completing correlation tests to validate the CEMS data against periodic stack testing methods. The methods approved for use in BC are listed in Table 8.2 below.

Similar application of approved methods occurs in the EU. There, the European Committee for Standardization (CEN) is the body responsible for approving methods. The EU-directive 2000/76/EC Annex III states that, If CEN standards are not available, then International Standards Association (ISO) standard methods would apply. Similar to the EPA methods, CEN stipulates that continuous measurement techniques must pass the CAL2 test, as described in EN14181, where the correlation between the actual concentration and continuous monitor result is verified by annual reference test.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 8: Emission Monitoring Systems

Table 8-2: Approved Emission Monitoring Methods

Contaminant	BC Approved Monitoring Methods	US EPA Proposed CIWSI Monitoring Methods	European Union Approved Monitoring Methods
Arsenic	EPA 108	–	EN14385
Cadmium	–	EPA 29	EN14385
Carbon Dioxide (CO ₂)	see Gas composition and molecular weight listing	–	US EPA Method 3A
Carbon Monoxide (CO)	EC c, EPA 10, EPA 10a, EPA 10b	EPA 10	EN14789
Continuous Emission Monitoring (certification/QA/QC)	EC d, EPA PS-1 to PS-7	–	EN14181
Gas composition and molecular weight (Orsat or fyrite)	EPA 3	–	
Gas composition and molecular weight (CO ₂ , O ₂ instrumental)	EPA 3a	–	
Gas composition and molecular weight (CO ₂ , O ₂ Orsat)	EPA 3b	–	
Hexavalent Chromium	EPA ALT 014, IC 306	–	EN 14385
Hydrogen Chloride (HCl) Halides and Halogens	EPA 26, EPA 26a EPA 26a is to be used when acid particulate matter is present in the emission	EPA 26a	EN1911
Lead (Pb)	EPA 12	EPA 29	EN14385
Mercury	EPA 101a	EPA 29, EPA30b	EN 13211
Metals (Ag, As, Cd, Cu, Mn, Ni, Pb, Sn, Ti, Zn)	EPA 29	–	EN14385
Moisture Content	EPA 4	–	En 14790
Nitrogen Oxides (NO _x)	EPA 7, EPA 7a, EPA 7c, EPA 7d, EPA 7e, EPA 20	EPA7E	EN14792
Opacity	EPA 9, EPA 9 alternative 1, MWLAP a, EPA 203 EPA 9 is the observation method; EPA 9 alternative 1 is the lidar method. EPA 203 is a proposed continuous method.	EPA 9	EN 13725
Organics (Total gaseous non-methane as carbon, grab)	EPA 25	–	
Organics (Speciation of hydrocarbons, grab)	EPA 18	–	EN13526 or VDI 3481, bl3 DIS 25140 (non methane)
Organics (polychlorinated biphenyls (PCBs) and other semi volatile organic compounds)	EC a	–	

Contaminant	BC Approved Monitoring Methods	US EPA Proposed CIWSI Monitoring Methods	European Union Approved Monitoring Methods
Organics (boiling point $\geq 100^{\circ}\text{C}$, semi-volatile organics (Semi-Vost), polychlorinated dibenzo-para-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs))	EC a, EPA 23	EPA 23	ISO 11338, part 1 En1948-1, modified
Organics (boiling point $\leq 100^{\circ}\text{C}$, volatile organics (VOST))	SW 0030	–	ISO 11338 (part 1+2), modified
Oxidants (ozone)	IC 411	–	
Oxygen (O_2)	See Gas composition and molecular weight listing	–	
Particulates	EC e, EPA 5, EPA 5d, EPA 5f	EPA 5, EPA 29	EN 14789
Particulates (Sizing)	EPA 201a	–	VDI 266, bl 1 ($>50 \text{ mg/Nm}^3$) EN13284-1 ($<50 \text{ mg/Nm}^3$)
Particulates (PM_{10})	EPA 201, EPA 201a	–	
Sampling site and traverse points	EC e, EPA 1	–	
Sampling site and traverse points (Stacks/ducts 4-12" diameter)	EPA 1a	–	
Sulphur dioxide (SO_2)	EPA 6, EPA 6a, EPA 6c	EPA 6, EPA6c	
Velocity and volumetric flow rate (Stacks/ducts $>12"$ diameter)	EC e, EPA 2	–	
Velocity and volumetric flow rate (Direct measurement)	EPA 2a, EPA 2d	–	ISO 10780
Velocity and volumetric flow rate (3-D probe)	EPA CTM 019	–	ISO 10780

It should be noted that if the above table is compared to emission limit parameters for WTE, monitoring methods are not noted for chromium, chlorophenols, chlorobenzene, polycyclicaromatic hydrocarbons, polychlorinated biphenyls, and total ACDD/F TEQ (Dioxins and Furans). Therefore, consideration should be given to research appropriate US EPA, Environment Canada or European Union Methods for adoption in the BC Field Sampling Manual.

8.4 Relationship between Monitoring Methods and Emission Limits

The setting of emission criteria must consider the monitoring method used to determine compliance and the period of time over which the sample is obtained. Emission limits based on periodic monitoring are typically lower than the emission limits based on CEMS. The reasons for this difference are described below.

In simple terms, periodic stack sampling generally involves sample runs for a minimum of 60 minutes for particulates or for dioxins, furans and other select air toxics a minimum of 240 minutes. A minimum of three sample runs constitutes a valid stack survey. Therefore, it can take between three and twelve hours to complete a single stack survey (not including time to set up and take down the equipment). During the test, the constituents of concern are collected continuously over the test period and the mass of the constituents collected is measured. The data is then reduced to generate a concentration value in a unit emission rate which is representative of the average concentration of the constituent over the sampling period.

Instantaneous fluctuations in the concentration of the constituents of concern in the emissions from incineration facilities occur as a result of a variety of factors, such as waste composition, moisture content, variations in feed rates, and the duration of the fluctuation is typically minutes or at most a few hours. Fluctuations in concentration during periodic monitoring test periods are averaged out and the average reported. Compliance is often determined by averaging the results of duplicate or triplicate tests, further normalizing the concentration in the emission.

Emission limits that are based on periodic sampling methods have a lower numerical value because the instantaneous fluctuations in the emission concentration are not identified individually but are averaged across the sampling period. The emission limits therefore correspond to the concentration that would be expected and achievable over the averaging period under normal facility operating conditions, including the fluctuations.

CEMS are by design continuous, with a high sampling frequency measured in seconds or minutes. CEMS will detect the instantaneous fluctuations in concentration and produces data over a short sampling interval, without averaging the results. CEMS provides a detailed glimpse of the emission quality and its variability over time. As a result, emission limits based on CEMS must take into account the expected fluctuations in emission quality and typically apply a much shorter averaging period (e.g., ½ hour) to accommodate the fluctuations. CEMS-based emission limits are set at a higher numerical value than periodic monitoring limits to accommodate the expected emissions fluctuations. Notwithstanding the higher numerical values, CEMS-based limits are equivalent to, or more protective than, the periodic sampling-based limit as they are generally applied over shorter averaging periods and as compliance with these limits can be more regularly demonstrated.

The US EPA establishes the CEMS-based limits by considering historical monitoring data from both periodic monitoring and CEMS and in the past has selected averaging periods between four hours and 24 hours based on statistical analysis of long-term CEMS data for a particular facility. Their default for setting CEMS-based limits is a 24-hour block average, calculated in accordance with EPA Method 19 of Appendix A-7 of 40 CFR Part 60.

8.5 Ambient Air Quality Monitoring

Ambient air quality monitoring stations are used to quantify concentrations of air contaminants in ambient air. The focus of ambient air monitoring is determining concentrations relative to ambient air quality objectives that have been established as being protective of human health and the environment. Ambient air quality monitoring does not measure emissions from any one source; rather it measures the combination of constituents in the atmosphere that may be present from any number of sources or locations. Point sources, fugitive emissions and even out-of-region emissions will be detected by ambient air quality monitoring. Ambient stations use a combination of continuous analyzers, typically for basic parameters and gas concentrations, and monitors that obtain a sample over an extended duration, for example total particulate and PM₁₀ and PM_{2.5}. Trends observed in air quality data are used to evaluate the effectiveness of reduction strategies for point source and non-point sources.

The Lower Fraser Valley Air Quality Monitoring Network is an excellent example of a regional ambient air quality monitoring. This network includes 27 long-term air quality monitoring stations operated by Metro Vancouver.^[190] Most of the stations collect air quality and weather data continuously. The six CACs reported continuously are: O₃, CO, SO₂, NO₂, PM₁₀, PM_{2.5}. Other pollutants that are less widely monitored include ammonia, VOCs, and Total Reduced Sulphur (TRS). Some stations collect non-continuous data for VOCs, particulate speciation and dichotomous particulates.^[191] In addition, Metro Vancouver deploys portable air quality stations and instruments to conduct special monitoring stations that focus on suspected problem areas in local communities.

Real-time ambient air quality monitoring data is also collected in the following BC communities:^[192]

- | | |
|-----------------------|--------------------------------------|
| ▪ Western Communities | ▪ Burns Lake |
| ▪ Victoria/Saanich | ▪ Terrace |
| ▪ Nanaimo/Parksville | ▪ Smithers |
| ▪ Campbell River | ▪ Fort St. John |
| ▪ Whistler | ▪ Fort Nelson |
| ▪ Williams Lake | ▪ Golden |
| ▪ Quesnel | ▪ Kamloops |
| ▪ Prince George | ▪ North, Central, and South Okanagan |

¹⁹⁰ Metro Vancouver Air Quality website: <http://www.metrovancouver.org/services/air/management/Pages/default.aspx>

¹⁹¹ Metro Vancouver. Technical Appendix Air Quality Data 2006. Accessible at: <http://www.bcairquality.com/readings/>

¹⁹² BC Air Quality Readings. Accessible at: <http://www.bcairquality.com/readings/>

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 8: Emission Monitoring Systems

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9 EMISSION LIMITS AND THEIR APPLICATION

9.1 Typical Regulatory Practices

This subsection contains an assessment of MSW-related emission limits from other jurisdictions. It indicates limits of all regulated substances plus determines which limits are dated, recent but derived from dated material, and recent. All limits have been classified as to whether they are representative of best achievable technology. Indications are made as to which technology is associated with the various limits. Most importantly, this section is intended to convey an understanding of not only the limits and appropriate control technologies that can meet these limits, but the rationale used to support setting these limits in other jurisdictions.

The key to examining the limits used in other jurisdictions for regulated substances is to understand not only the limits and appropriate control technologies that can meet these limits, but the rationale used to support setting these limits in other jurisdictions. In some cases, the limits can be risk-based with appropriate provisions for emissions to fall well within those that can cause an effect. In others, the limits are set based on MACT (i.e., BAT) to drive the use of best-practice control technologies, or are set at in-stack detection limits representing the limit of our capability to determine if a parameter is being emitted at all. Understanding the premise behind the regulatory practices, limits or standards set in other jurisdictions, will assist in the development of the supporting rationale for the updated provincial air emission criteria in BC.

Section 9 presents the regulatory approach applied in various jurisdictions which represent a range of jurisdictions in which WTE is applied. In preparation of this report, it was not intended to provide a summary of the regulatory approach applied in all jurisdictions in which WTE is applied, but instead to present information for a sampling of jurisdictions that generally fit the following requirements:

1. Jurisdictions located adjacent to BC (e.g., Alberta, Washington State, etc.) where the regulatory approach to emissions represents those that could affect connected airsheds.
2. Jurisdictions within Canada within which the Canada Wide Standards developed by the Canadian Council of the Ministers of the Environment (CCME) forms a foundation for the regulatory environment, where there have been appropriate modifications to reflect provincial specific issues, and where there has been more recent review of WTE approaches (e.g., Alberta, Ontario).
3. Other nations (e.g., USA, and various EU nations) where WTE is widely applied, where regulatory approaches have been relatively frequently updated over the past 20 years, and from which facility performance information and reasonable translations of the regulations and supporting documents are readily available.

There are a number of Asiatic nations (Japan, South Korea, China and others) where WTE has also been widely applied, and where some information is available regarding current approaches and technologies, however, sourcing facility performance data and/or reasonable translations of regulations and supporting documents that discuss the regulatory approach is very difficult. While

some research was undertaken, reliable consistent information from many other nations was not available to support this project.

9.1.1 Regulatory Environment in Canada

The Canadian Council of the Ministers of the Environment (CCME) has developed guidelines and Canada Wide Standards (CWS) that deal with the release of air emission from WTE facilities. It has also developed ambient air quality CWS for particulate matter and ozone. The following subsections discuss each.

9.1.1.1 CCME Guidelines

The Canadian Council of Ministers of the Environment (CCME) has developed federal guidelines which give a basis for acceptable levels of emissions for a number of substances of concern (total particulate matter, hydrogen chloride, carbon monoxide, sulfur dioxide, nitrogen oxides, cadmium and lead) that are released from WTE facilities. The 1989 CCME guidelines were developed because the CCME recognized the potential for significant growth in the area of MSW incineration in Canada and wanted to ensure that health and environmental concerns were addressed. Specific guidelines for each parameter are listed in Table 8-1.^[193]

Although the CCME has developed these guidelines, it has no authority to impose its guidelines on any jurisdiction in Canada. The guidelines, therefore, act more as a measure to which the provinces and territories can compare their own individual limits. Each province or territory decides on the degree to which it will incorporate the CCME suggested pollution guidelines in their own laws. Due to the CCME guidelines lack of authority, there is a large degree of variation of environmental standards across the country in terms of emissions from incineration facilities.

9.1.1.2 CCME Canada Wide Standards (CWS)

Canada-wide Standards (CWSs) are intergovernmental agreements developed under the Canadian Council of Ministers of the Environment (CCME) Canada-wide Environmental Standards Sub-Agreement, which operates under the broader CCME Canada-wide Accord on Environmental Harmonization. National ambient air quality objectives can be promulgated by Health Canada and/or by Environment Canada under the *Canadian Environmental Protection Act* (CEPA). CWSs address key environmental protection and health risk issues that require concerted action across Canada. CWSs represent co-operation toward a common goal and involve no delegation of authority by any federal, provincial or territorial Minister of Environment.

CWSs can include quantitative standards for protecting the environment and reducing risks to human health. The focus of the Canada-wide Environmental Standards Sub-Agreement is on standards that recommend concentrations of substances in the environment. The standards generally provide protection for human health and the environment, and are technologically and economically achievable.

¹⁹³ Canadian Council of Ministers of the Environment. Operating and Emissions Guidelines for MSW Incinerators Report CCME-TS/WM-TRE003, June 1989.

In addition to the 1989 CCME Guidelines, the CCME has developed Canada Wide Standards in regards to emissions of mercury and dioxins/furans from municipal waste incineration.^[194] In 2000, the CCME also developed ambient air quality CWS for particulate matter and ozone.^[195]

Mercury (Hg)

The standards for mercury emissions were endorsed in 2000 and address both existing and new facilities that incinerate waste. In their report, the CCME identified waste incineration as one of the three main sectors contributing to mercury emissions in Canada but stressed that these emissions are mainly associated with the incineration of sewage sludge and hazardous waste. The CCME set mercury emissions limits at 20 µg/Rm³.

Dioxins/Furans (PCDD/F)

The standards for dioxin and furan concentrations were endorsed in 2001. In their report, the CCME identified the incineration of municipal waste, sewage sludge, medical waste, and hazardous waste as major contributors to the emissions of dioxins and furans in Canada. The CCME set dioxin/furan emissions limits at 80 pg I-TEQ/Rm³.^[196]

The CCME also provides a number of recommendations regarding reduction of emissions of dioxins and furans from the incineration of municipal waste. Their recommendations included increasing the diversion of waste from disposal, removing materials from the waste stream that have a great potential to lead to increased emissions of dioxins and furans, combustion control strategies to optimize performance, and use of alternative disposal or management technologies.^[197]

In 2007, the CCME reviewed their CWS for dioxins/furans and determined that there is no need to update the emission limit. They reasoned that the current limit for dioxins/furans is still below limits put in place by other jurisdictions around the world such as the European Union (92 pg I-TEQ/Rm³).^[198]

Ambient Particulate Matter and Ozone

In addition to the guidelines for emission of total particulate matter from municipal solid waste incinerators set out in 1989^[199], the CCME also developed ambient air quality CWS for particulate matter (PM) and ozone in 2000.^[200] The CWS set an overall ambient target for PM_{2.5} for 2010 at 30 µg/Rm³ (24-hour averaging time based on the 98th percentile ambient measurement annually averaged over three consecutive years). The CWS does not set stack or industry sector specific targets.

¹⁹⁴ Canadian Council of Ministers of the Environment. Canada-Wide Standards for Mercury Emissions. June 2000

¹⁹⁵ Canadian Council of Ministers of the Environment Canada-Wide Standards for Particulate Matter (PM) and Ozone. 2000

¹⁹⁶ Canadian Council of Ministers of the Environment Canada-Wide Standards for Dioxins and Furans. 2001

¹⁹⁷ Canadian Council of Ministers of the Environment Canada-Wide Standards for Dioxins and Furans. 2001.

¹⁹⁸ Canadian Council of Ministers of the Environment (CCME). (2007). Review of Dioxins and Furans from Incineration In Support of a Canada-wide Standard Review

¹⁹⁹ Canadian Council of Ministers of the Environment. Operating & Emissions Guidelines for MSW Incinerators Report CCME-TS/WM-TRE003, June 1989.

²⁰⁰ Canadian Council of Ministers of the Environment Canada-Wide Standards for Particulate Matter (PM) and Ozone. 2000.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 9: Emission Limits and Their Application

The CWS did not provide an overall ambient target for PM₁₀ as the CCME considered the reduction in PM₁₀ to come along with a reduction in PM_{2.5}. Therefore the report does not discuss total particulate matter, or PM_{2.5}.

The CCME reviewed its CWS for particulate matter (PM) and ozone in 2005 and recommended keeping the 2000 targets.^[201]

9.1.1.3 CEAA

The federal requirements for an environmental assessment arise from the *Canadian Environmental Assessment Act* (CEAA) and its supporting regulations. CEAA requires the Government of Canada to consider the environmental effects of proposed projects before making a decision or exercising any regulatory power in relation to a project. Per section 5(1) of CEAA, the federal environmental assessment process is generally triggered if the Government of Canada:

- Is the proponent
- Provides funding, loan or other financial assistance that enables a project
- Sells or leases land to enable a project
- Issues a permit, licence, approval, or authorization that is identified in the Law List Regulations pursuant to CEAA.

If future WTE projects fall under the above triggers, a CEAA-compliant environmental impact assessment will be required.

9.1.1.4 Summary

Overall, the national guidelines set by the CCME are quite conservative in comparison to the laws and guidelines set by other countries on similar pollutants. However, because the CCME does not have the authority to enforce their standards and guidelines, it limits their ability to ensure that targets are being met. Responsibility for ensuring the environmental performance of WTE facilities rests with provincial and territorial governments.

Table 9-1 presents an overview of the CCME emissions guidelines and CWS applicable to municipal solid waste incinerators.

Table 9-1: CCME WTE Emissions Guidelines for Municipal Solid Waste Incinerators (1989)

Contaminant	Concentration Units	Canadian Council of Ministers of the Environment (CCME) Guidelines/CWS
Total Particulate Matter (TPM)	mg/Rm ³ @ 11% O ₂	20 ¹
Sulphur Dioxide (SO ₂)	mg/Rm ³ @ 11% O ₂	260 ²
Hydrogen Chloride (HCl)	mg/Rm ³ @ 11% O ₂	75 or 90% removal ¹
Nitrogen Oxides (NO _x) (as NO ₂)	mg/Rm ³ @ 11% O ₂	400 ²
Carbon Monoxide (CO)	mg/Rm ³ @ 11% O ₂	57 (114 for RDF Systems) ¹

²⁰¹ Joint Action Implementation Coordinating Committee (JAICC). (2005). An Update in Support of the Canada-wide Standards for Particulate Matter and Ozone

Contaminant	Concentration Units	Canadian Council of Ministers of the Environment (CCME) Guidelines/CWS
Cadmium (Cd)	µg/Rm ³ @ 11% O ₂	100 ²
Lead (Pb)	µg/Rm ³ @ 11% O ₂	50 ²
Mercury (Hg)	µg/Rm ³ @ 11% O ₂	20 ³
PCDD/F TEQ (Dioxins and Furans)	ng/Rm ³ @ 11% O ₂	0.08 ⁴
Opacity	%	5 ⁵

NOTES:

N. Def. = Not Defined

¹ CCME Operating and Emissions Guidelines for MSW Incinerators Report CCME-TS/WM-TRE003, June 1989. Table 4.2: Stack Discharge Limits (at 11% O₂)

² CCME Operating and Emissions Guidelines for MSW Incinerators Report CCME-TS/WM-TRE003, June 1989. Table 4.3: Anticipated Emissions from MSW Incinerators Operating Under Good

³ CCME Canada-Wide Standards for Mercury Emissions (2000)

⁴ CCME Canada-Wide Standards for Dioxins and Furans (2001)

⁵ CCME Operating and Emissions Guidelines for MSW Incinerators Report CCME-TS/WM-TRE003, June 1989. Section 4.3.2.

9.1.2 Regulatory Environment in British Columbia

This section summarizes the regulatory requirements that apply to existing and new WTE facilities in BC.

9.1.2.1 *Environmental Management Act*

The *Environmental Management Act* (EMA) is a relatively new piece of legislation in BC. It was brought into force on July 8, 2004 to replace the *Waste Management Act* and the (previous) *Environment Management Act*. It brings provisions from both *Acts* into one statute and covers a broad range of environmental management aspects including:

- Waste disposal (covering air emissions, effluent discharges and solid wastes)
- Hazardous waste management
- Municipal waste management
- Contaminated sites remediation
- Remediation of mineral exploration sites and mines.

Under sections 3(2) and 3(3), any introduction of waste into the environment requires authorization via permit or approval. Activities that necessitate a permit are prescribed through the *Waste Discharge Regulation* (WDR). In addition, emissions or discharges from industries that are not considered to pose a high risk for environmental damage have province-wide codes of practice established to govern operation.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 9: Emission Limits and Their Application

The WDR defines “prescribed” industries, trades, businesses, activities and operations for the purposes of regulation under EMA section 6(2) and 6(3). It also provides a process for registering under a Minister’s code of practice and a process for substituting requirements to a code of practice in order to protect the public or the environment if an applicant can prove that the intent of the code will be met.

The EMA and the WDR established a three-tiered approach for discharges to the environment by prescribed industries. Tier 1 industries, which would include the WTE sector, are considered to pose an elevated risk to the environment and public health and therefore require a permit to discharge to the environment or for the case of WTE facilities under a Solid Waste Management Plan (under Part 3 of EMA). Tier 2 industries pose a lower risk and discharges can be addressed by a Code of Practice or by a permit. Tier 3 industries are low risk and do not require a permit.

Following submission of the EMA permit application, Ministry staff review the technical assessment reports and application form information in order to draft recommendations for the Director of Waste Management. The applicant reviews the draft recommendations, at which point the Director makes a decision to either grant or deny a permit.

Should a permit be granted, the permit holder must pay an annual fee on the anniversary date of its issuance, or 30 days after the date an invoice has been issued for the amount owing. The annual permit fee is a combination of a base fee and a variable fee based on contaminants from authorized discharges identified in the permit.

Under the EMA, Part 3 (Municipal Waste Management), municipal Solid Waste Management Plans (SWMPs) are submitted for approval to the minister^[202]. Once the plan is approved by the minister, an operational certificate may be issued by the Director to the municipality or specific facility covered by the SWMP. A power or authority similar to a permit may be exercised by a director in reference to an operational certificate. SWMPs address the management of solid waste in landfills as well as WTE facilities. Once a SWMP containing specific emission limits for a WTE facility is approved by the Director, the facility would not require a permit from BCMOE.

9.1.2.2 Emission Criteria for Municipal Solid Waste Incineration

BC Ministry of Environment introduced Emission Criteria for Municipal Solid Waste Incinerators^[203] in 1991. A copy of the 1991 emissions criteria document can be found in Appendix B of this report. The respective incinerator stack emissions limits are summarized in Table 9-2 and apply to new and modified MSW incinerators with a capacity of greater than 400 kg/h (essentially equivalent to 9.6 tonnes per day) of waste. If the incinerator processing capacity is equal or less than 400 kg/h of waste, different emission limits and ambient air quality objectives apply (Table 8-3).

The criteria require continuous monitoring of combustion temperature, oxygen, CO, opacity, HCl, and emission control device inlet and outlet temperatures. Monthly source testing and annual performance reporting are also required.

²⁰² BC *Environmental Management Act*. Chapter 53. Part 3 – Municipal Waste Management. 2010.

²⁰³ BC Ministry of Environment. Emission Criteria for Municipal Solid Waste Incinerators. 1991.

The BC Emission Criteria for Municipal Solid Waste Incinerators also identify design and operation requirements for MSW and emission control systems to minimize emissions from an incinerator. Table 9-2 lists incinerator design and operation parameters applicable to all sizes of incinerators.

Information pertaining to the permitting of the Burnaby WTE Incinerator in comparison to BC Emission Criteria for Municipal Solid Waste Incinerators is provided in Section 9.1.3.2.

Table 9-2: BCMOE Emissions Criteria for MSW with a Processing Capacity Greater than 400 kg/h of Waste (1991)

Contaminant	Concentration Units	Emissions Criteria	Averaging Period	Monitoring Method
Total Particulate Matter (TPM)	mg/Rm ³ @ 11% O ₂	20	1	2
Carbon Monoxide (CO)	mg/Rm ³ @ 11% O ₂	55 ³	4-hour rolling average	Continuous monitoring
Sulphur Dioxide (SO ₂)	mg/Rm ³ @ 11% O ₂	250	1	2
Nitrogen Oxides (NO _x as NO ₂)	mg/Rm ³ @ 11% O ₂	350	1	2
Hydrogen Chloride (HCl)	mg/Rm ³ @ 11% O ₂	70	8-hour rolling average	Continuous monitoring
Hydrogen Fluoride (HF)	mg/Rm ³ @ 11% O ₂	3	1	2
Total Hydrocarbons (as CH ₄)	mg/Rm ³ @ 11% O ₂	40	1	2
Arsenic (As) ⁴	µg/Rm ³ @ 11% O ₂	4	1	2
Cadmium (Cd) ⁴	µg/Rm ³ @ 11% O ₂	100	1	2
Chromium (Cr) ⁴	µg/Rm ³ @ 11% O ₂	10	1	2
Lead (Pb) ⁴	µg/Rm ³ @ 11% O ₂	50	1	2
Mercury (Hg)	µg/Rm ³ @ 11% O ₂	200	1	2
Chlorophenols	µg/Rm ³ @ 11% O ₂	1	1	2
Chlorobenzenes	µg/Rm ³ @ 11% O ₂	1	1	2
Polycyclicaromatic Hydrocarbons	µg/Rm ³ @ 11% O ₂	5	1	2
Polychlorinated Biphenyls	µg/Rm ³ @ 11% O ₂	1	1	2
Total PCDD/F TEQ (Dioxins and Furans) ⁵	ng/Rm ³ @ 11% O ₂	0.5	1	2
Opacity	%	5	1hr avg, data every 10 sec	Continuous monitoring

NOTES:

BC Limits are based on 20°C.

¹ To be averaged over the approved sampling and monitoring method

² All sampling and monitoring methods, including continuous monitors, are to be approved by the Regional Manager.

³ For RDF systems the limit shall be 110 mg/m³

⁴ The concentration is total metal emitted as solid and vapour

⁵ Expressed as Toxicity Equivalents. The value shall be estimated from isomer specific test data and toxicity equivalency factors by following a procedure approved by the Minister

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 9: Emission Limits and Their Application

BC has remote camps serving the resource industry. In many of these locations, domestic solid waste is incinerated in commercially available units with capacities less than 400 kg/h. Typically these are small units that operate intermittently and which have small diameter discharge stacks that may be difficult to conduct periodic or continuous source testing. For these facilities, the emission limits for particulate is less stringent than for larger facilities (180 mg/m³ for smaller facilities versus 20 mg/m³ for larger facilities) reflecting the absence of APC equipment to control particulate. The carbon monoxide limit is the same as 55 mg/m³ for large and small facilities where the fuel is MSW, but increases to 110 mg/m³ for small facilities burning RDF. This is intended to reflect less efficient combustion of RDF, which may include fuel with higher moisture content.

Under the BC Waste Discharge Regulation^[204], the emissions and ash from a commercially available auxiliary fuel fired refuse incinerator serving remote industrial, recreational, exploration or construction camp designed to accommodate fewer than 100 persons are exempt from the application of Environmental Management Act for waste disposal (Section 6(2) and 6(3)).^[205] In such instances, the emissions criteria defined in Table 8-3 are not applied.

The capacity limit of 400 kg/h (9.6 tonnes per day) has been a reasonable cut-off for the commercially available incinerators used in remote camps in BC. We noted that the US Environmental Protection Agency defines small as 250 tons per day or less and large facilities as greater than that. In Ontario, a simpler approval process applies to facilities that process less than 100 tonnes per day, however, the same air emissions criteria apply regardless of size for permanent facilities. There is some flexibility associated with temporary or research facilities. The BC Environmental Assessment Act trigger to conduct an Environmental Assessment is 250 tonnes per day. The concept of a low threshold in terms of facility size, as applied in BC and Ontario, is a reasonable one, affording a higher level of protection to the environment for all facilities that fall outside the scale for research or on-site materials management. Determining the appropriate cut-off capacity should be based on the regional context. In BC, small incinerators will in most all cases be associated with remote camps serving the resource sector, and not operating as commercial incineration facilities. It should be recognized that facilities below the capacity cut-off generally are too small for point source emission monitoring, so the limit needs to be set appropriately. While there is no direct connection between the facility size cut-off in the 1991 Criteria and the WDR exemption, the current 400 kg/h cutoff should be maintained in the BC context in the revised MSWI Criteria.

²⁰⁴ BC *Environmental Management Act*. Waste Discharge Regulation. 2008. Website:
http://www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/50_320_2004#section6

²⁰⁵ BC *Environmental Management Act*. May 5, 2010. Website:
http://www.bclaws.ca/EPLibraries/bclaws_new/document/ID/freeside/03053_02

Table 9-3: BCMOE Emissions Criteria for MSW with a Processing Capacity Equal to or Less than 400 kg/h of Waste (1991)

Contaminant	Concentration Units	Emissions Criteria	Averaging Period	Monitoring Method
Total Particulate Matter (TPM)	mg/Rm ³ @ 11% O ₂	180	1	2
Carbon Monoxide (CO)	mg/Rm ³ @ 11% O ₂	55 ³	4-hour rolling avg	Continuous
Carbon Monoxide (if burning RDF)	mg/Rm ³ @ 11% O ₂	110	4-hour rolling avg	Continuous
Sulphur Dioxide (SO ₂)	µg/Rm ³ @ 11% O ₂	450	1	2
Nitrogen Oxides (NO _x as NO ₂)	µg/Rm ³ @ 11% O ₂	400	1	2
Hydrogen Chloride (HCl)	µg/Rm ³ @ 11% O ₂	100	8-hour rolling avg	Continuous
Hydrogen Fluoride (HF)	mg/Rm ³ @ 11% O ₂	3	1	2
Opacity	%	10		

NOTES:

BC Limits are based on 20°C.

¹ To be averaged over the approved sampling and monitoring method

² All samples and monitoring methods, including continuous monitors, are to be approved by the Regional Manager

³ For RDF systems the limit shall be 110 mg/m³

Table 9-4: BCMOE Design and Operation Requirements for MSW and Emission Control Systems

Parameter	Incinerator Type Modular (Excess Air and Starved Air)	Incinerator Type	
		Mass Burn	RDF
Incinerator			
Minimum Incineration Temperature	1,000°C at fully mixed height	1,000°C determined by an overall design review	1,000°C
Minimum Residence Time	One second after final secondary air injection ports	1 second calculated from the point where most of the combustion has been completed and the incineration temperature fully developed	1 second calculated from point where most of the combustion has been completed and the incineration temperature fully developed
Primary Air (Underfire)	Utilize multi-port injection to minimize waste distribution difficulties	Use multiple plenums with individual air flow control	Use air distribution matched to waste distribution
Secondary Air (Overfire)	Up to 80% of total air required ¹	At least 40% of total air required	At least 40% of total air required
Overfire Air Injector Design	That required for penetration and coverage of furnace cross-section	That required for penetration and coverage of furnace cross-section	That required for penetration and coverage of furnace cross-section

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 9: Emission Limits and Their Application

Parameter	Incinerator Type Modular (Excess Air and Starved Air)	Incinerator Type	
		Mass Burn	RDF
Auxiliary Burner Capacity	Secondary burner 60% of total rated heat capacity, and that required to meet start-up and part-load temperatures	60% of total output, and that required to meet start-up and part-load temperatures	60% of total output, and that required to meet start-up and part-load temperatures
Oxygen Level at the Incinerator Outlet	6 to 12%	6 to 12%	3 to 9%
Turndown Restrictions	80 to 110% of designed capacity	80 to 110% of designed capacity	80 to 110% of designed capacity
Maximum CO Level	55 mg/m ³ @ 11% O ₂ (4-h rolling average)	55 mg/m ³ @ 11% O ₂ (4-h rolling average)	110 mg/m ³ @ 11% O ₂ (4-h rolling average)
Emission Control Systems²			
Flue Gas Temperature at Inlet or Outlet of Emission Control Device ³	Not to exceed 140°C	Not to exceed 140°C	Not to exceed 140°C
Opacity ⁴	Less than 5%	Less than 5%	Less than 5%

NOTES:

¹ For excess Air type – as required by design.

² Applicable to incinerators equipped with such systems

³ The flue gas temperature at the inlet or outlet will depend on the type of emission control device in use

⁴ For incinerators with capacity or processing 400 kg/h or less of waste the opacity shall be less than 10%

9.1.2.3 BC Ambient Air Quality Objectives

The BC Ambient Air Quality Objectives (BC AAQO) have been derived from a variety of agencies on a provincial and national basis. It is the intention that the BC AAQO are at least consistent with, and potentially more stringent than, air quality objectives adopted on a national basis. As described above, national air quality objectives can be promulgated by either Health Canada or Environment Canada. It should be noted that the AAQO are non-statutory limits that are intended to be used as benchmarks to assess air quality and to guide decision making with respect to the management of air quality within an airshed.

The BC Ministry of Environment (2006), the federal government and Metro Vancouver established ambient air quality criteria for a number of air contaminants. The BC AAQO for particulate matter PM_{2.5} were adopted by the Ministry of Healthy Living and Sport (BC MHLS, 2009).^[206] These objectives are summarized in Table 8-5.

²⁰⁶ BC Ministry of Healthy Living and Sport. Air Quality Objectives for British Columbia and Canada. April, 2009
<http://www.env.gov.bc.ca/epd/bcairquality/regulatory/pm25-objective.html>

Historically, national air quality objectives^[207] have been defined as follows:

- The **Maximum Desirable Level** is the long-term goal for air quality and provides a basis for anti-degradation policy for unpolluted parts of the country, and for the continuing development of control technology.
- The **Maximum Acceptable Level** provides adequate protection against effects on soil, water, vegetation, materials, animals, visibility, personal comfort and well-being.
- The **Maximum Tolerable Level** denotes time based concentrations of air contaminants beyond which, due to a diminishing margin of safety, appropriate action is required to protect the health of the general population.

The BC AAQO are denoted as Levels A, B, and C and generally defined as follows:

- **Level A** is set as the objective for new and proposed discharges and, within the limits of best practicable technology, to existing discharges by planned staged improvements for these operations.
- **Level B** is set as the intermediate objective for all existing discharges to meet within a period of time specified by the Director, and as an immediate objective for existing discharges which may be increasing in quantity or altered in quality as a result of process expansion or modification.
- **Level C** is set as the immediate objective for all existing chemical and petroleum industries to reach within a minimum technically feasible period of time.

Metro Vancouver adopted its own Ambient Air Quality Objectives as part of the Air Quality Management Plan (AQMP) in October, 2005. AAQO were set for carbon monoxide, nitrogen dioxide, sulphur dioxide, ozone, inhalable particulate matter (PM₁₀), and fine particulate matter (PM_{2.5}).^[208] In 2008, Metro Vancouver's objectives were equivalent or more stringent than both the CWS and BC objectives for these CACs.^[209] A provincial 24-hour AAQO for PM_{2.5} was established in 2009 and is numerically the same as Metro Vancouver's objective. However, whereas exceedance is prohibited under the Metro Vancouver objective, some exceedances are permissible under the BC objective each year. Metro Vancouver's annual objective is less stringent than the provincial annual target of 8 µg/m³ and an annual planned goal of 6 µg/m³.

²⁰⁷ Health Canada. National Ambient Air Quality Objectives. <http://www.hc-sc.gc.ca/ewh-semt/pubs/air/naago-onqaa/index-eng.php>

²⁰⁸ Greater Vancouver Regional District (GVRD). Air Quality Management Plan. September 2005

<http://www.metrovancouver.org/about/publications/Publications/AQMPSeptember2005.pdf>

²⁰⁹ Metro Vancouver. 2008 Lower Fraser Valley Air Quality Report. June, 2009

<http://www.metrovancouver.org/about/publications/Publications/LowerFraserValleyAmbientAirQuality-2008.pdf>

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 9: Emission Limits and Their Application

Table 9-5: British Columbia, National and Metro Vancouver Ambient Air Quality Objectives

Contaminant	Averaging Period	BC Objectives ($\mu\text{g}/\text{m}^3$)			Canada Objectives ($\mu\text{g}/\text{m}^3$)			Metro Vancouver Objectives ($\mu\text{g}/\text{m}^3$)
		Level A	Level B	Level C	Maximum Desirable	Maximum Acceptable	Maximum Tolerable	Objective Level
Sulphur Dioxide (SO_2)	1-hour	450	900	900 – 1,300	450	900	NA	450
	3-hour	375	665	NA	NA			NA
	24-hour	160	260	360	150	300	800	125
	Annual	25	50	80	30	60	NA	30
Total Reduced Sulphur (TRS)	1-hour	7	28	NA	NA			7 ⁴
	24-hour	3	6	NA	NA			NA
Hydrogen Sulphide (H_2S)	1-hour	7.5 – 14	28 – 45	42 – 45	1	15	NA	NA
	24-hour	4	6 – 7.5	7.5 – 8	NA	5	NA	NA
Nitrogen Dioxide (NO_2)	1-hour	NA	NA	NA	NA	400	1,000	200
	24-hour	NA	NA	NA	NA	200	300	NA
	Annual	NA	NA	NA	60	100	NA	40
Carbon Monoxide (CO)	1-hour	14,300	28,000	35,000	15,000	35,000	NA	30,000
	8-hour	5,500	11,000	14,300	6,000	15,000	20,000	10,000
Ozone (O_3)	1-hour	NA			100	160	300	NA
	8-hour	NA			65 ppb ³			126
	24-hour	NA			30	50	NA	NA
	Annual	NA			NA	30	NA	NA
PM _{2.5}	24-hour	25 ¹			30 ²			25
	Annual	8			NA			12
PM ₁₀	24-hour	50			NA			50
	Annual	NA			NA			20

Contaminant	Averaging Period	BC Objectives ($\mu\text{g}/\text{m}^3$)			Canada Objectives ($\mu\text{g}/\text{m}^3$)			Metro Vancouver Objectives ($\mu\text{g}/\text{m}^3$)
		Level A	Level B	Level C	Maximum Desirable	Maximum Acceptable	Maximum Tolerable	Objective Level
Total Suspended Particulates (TSP)	24-hour	150	200	260	NA	120	400	NA
	Annual	60	70	75	60	70	NA	NA
Lead (Pb)	24-hour	4	4	6	NA			NA
	Annual	2	2	3	NA			NA
Formaldehyde (CH_2O)	1-hour	Action Level = 60			NA			NA
	24-hour	Action Level = 370			NA			NA

NOTES:

Sources: BC MHLS (2009, Internet Site), Health Canada (2007), Metro Vancouver (2008 Lower Fraser Valley Ambient Air Quality, 2006 Technical Appendix Air Quality Data, 2005 Air Quality Management Plan for Greater Vancouver).

NA = Not applicable

¹ Based on 98th percentile value for one year.

² The Canada-wide Standard is referenced to the 98th percentile value averaged over three consecutive years.

³ 8-hour daily maximum is based on fourth highest annual value, average over three consecutive years.

⁴ Metro Vancouver TRS desirable, acceptable and tolerable levels are 7, 14 and 1414 $\mu\text{g}/\text{m}^3$, respectively.

9.1.2.4 BCMOE Best Achievable Technology Policy

In May 2008, the BC Ministry of Environment adopted an interim policy for “Determining Best Achievable Technology Standards”.^[210] The policy is intended to provide guidance to MOE staff when setting waste discharge standards, provincial targets, regulations and codes of practice, by using the best achievable technologies (BAT) appropriate for the sector. BAT is also to be used by staff in the setting of facility-specific permit or approval limits. The interim BAT policy is meant to encourage the scoping of all technology shown to be economically feasible through successful commercial application in a similar facility in the same industry. New and innovative technologies must also be examined. Generally, BAT will be applied to new facilities, facilities undergoing major modifications that will result in amendments to their permits and/or facilities located in sensitive environments.

The interim policy identifies seven steps to the determination of BAT to be used in the setting of standards and criteria for the province and for facilities. These steps include:

1. Identification of all potential technologies or options
2. Eliminating technically infeasible options
3. Consideration of the reliability of each option
4. Ranking of technically feasible options by control effectiveness
5. Evaluating the cost effectiveness of each option
6. Selection of the appropriate BAT for the specific application
7. Determine the appropriate waste discharge criteria or standard.

The interim BAT policy does not specify the appropriate technology for any given application, rather the approach is to determine what discharge quality is technically and economically possible and allow proponents to select equipment and processes that meet those criteria.

9.1.2.5 British Columbia Environmental Assessment Act

The British Columbia *Environmental Assessment Act* (BCEAA) governs the preliminary environmental approval process for large capital projects in BC and includes consideration of new projects, modifications to existing facilities, and dismantling and abandonment of facilities. BCEAA is administered by the British Columbia Environmental Assessment Office (BCEAO) and is intended to ensure that projects subject to the legislation meet the Province of British Columbia’s goals of environmental, economic, and social sustainability. BCEAA also provides a process to address issues and concerns raised by the public, First Nations, interested stakeholders and government agencies.

Future WTE facilities may require approval under the BCEAA if they meet the criteria set out in the Reviewable Projects Regulation^[211] under Part 4 (Energy Projects) and Part 6 (Waste Disposal Projects) of the regulation. BCEAA Reviewable Projects Regulations applicable to WTE projects are

²¹⁰ BCMOE Interim Policy: Determining Best Achievable Technology Standards, May 2008

²¹¹ *British Columbia Environmental Assessment Act*: Reviewable Projects Regulation. BC. Reg. 370/2002. Amended January 14, 2010

summarized in Table 9-6. The BC Environmental Assessment Office (EAO) has indicated that future WTE facilities will require BCEAA approval if they trigger one or both of the criteria defined under Part 4 and 6 of the Reviewable Projects Regulation.^[212]

Table 9-6: BCEAA Reviewable Projects Regulation Applicable to WTE Projects

Project Category	New Project	Modification of Existing Project
Part 4 – Power Plant	Criteria: (1) A new facility with a rated nameplate capacity of ≥ 50 MW of electricity that is (a) a hydroelectric power plant (b) a thermal electric power plant, or (c) another power plant	Criteria: (1) Modification of an existing facility that results in the facility having a rated nameplate capacity that has increased by ≥ 50 MW of electricity
Part 6 – Local Government Solid Waste Management	Criteria: (1) A new facility if (a) The board of a regional district has determined that the facility will be included in a solid waste management plan or a solid waste management plan amendment to be submitted to the minister responsible for the administration of the <i>Environmental Management Act</i> for approval as part of the Regional Solid Waste Management Planning Process, and (b) The facility is for the treatment or disposal of municipal solid waste by the operation of: (i) a landfill with a design capacity of $> 250\,000$ tonnes/year, or (ii) an incinerator with a design capacity of > 225 tonnes/day.	Criteria: (1) Modification of an existing facility if the board of a regional district has determined that the modification will be included in a solid waste management plan or a solid waste management plan amendment to be submitted to the minister responsible for the administration of the <i>Environmental Management Act</i> for approval as part of the Regional Solid Waste Management Planning Process, and the criteria in either (a) or (b) are met: (a) The modification of the existing facility if (i) the existing facility, were it a new facility, would meet the criteria described opposite in Column 2, section (1) (b) (i), (ii) the modification results in (A) an extension in the lifespan of the facility beyond that lifespan currently authorized in an approved solid waste management plan, or (B) an increase in the annual design capacity of the facility beyond that currently authorized in an approved solid waste management plan; (b) Does not meet the criteria described in Column 2, subsection (1) (b) (i) or (ii) for a new facility, but the modification results in an increase in the design capacity of the facility above the threshold under Column 2, subsection (1) (b) (i) or (ii).

²¹² Per. Comm. Chris Hamilton, EAO, and Ward Prystay, Stantec. February 26, 2010

9.1.3 Regulatory Environment in Metro Vancouver

9.1.3.1 Greater Vancouver Regional District Air Quality Management Bylaw No. 1082, 2008

The Greater Vancouver Regional District (GVRD, recently renamed to Metro Vancouver) has been authorized by the *Environmental Management Act* to regulate, control and prevent discharge of air contaminants. The Greater Vancouver Regional District Air Quality Management Bylaw No. 1082^[213] regulates the discharge of air contaminants within Metro Vancouver. The bylaw dictates air emissions from industries, trades, businesses, activities, operations or residences are required to obtain approval from the District Director whether or not they are permitted under the *Environmental Management Act*. Waste management facilities must fulfill the requirements defined by the District Director in order to obtain authorization to discharge air contaminants from the Provincial Government.

The Burnaby Incinerator operates under the Metro Vancouver Solid Waste Management Plan, and as such the above MV bylaw does not apply to the Burnaby Incinerator.

9.1.3.2 Metro Vancouver Solid Waste Management Plan

Specific objectives on reducing per capita garbage disposal in the Greater Regional Vancouver District (now Metro Vancouver) were set by the province of BC in 1995. The objectives were published in the 1995 Greater Waste Regional Solid Waste Management Plan^[214] report, stating per capita garbage disposal will be reduced by at least 30% in 1995 and 50% in 2000, while responsibly managing any residues. As part of the objectives, Appendix D of the report summarized long-term monitoring requirements and discharge limits for the Burnaby Incinerator disposal facility.

The Metro Vancouver Burnaby incinerator burns approximately 280,000 tonnes of garbage to produce 900,000 tonnes of steam which is used to generate electricity. The plant has three processing lines, each processing approximately 11.5 tonnes of garbage each hour. Generated heat and gases are passed into the boiler area, where they heat tubes filled with water. Gases subsequently pass into the flue gas cleaning system which consists of the lime and carbon injection reactor and fabric bags. The lime and carbon injection reactor captures acid gases and any traces of mercury. Fabric bags are used to remove acids and particulate matter before the cleaned gas is discharged through the 60 m high stack.

Table 9-7 compares the air discharge limits against actual Burnaby incinerator air emissions.^[215] The table also summarizes the long-term monitoring requirements as well as the monitoring techniques used at the facility.^[216, 217]

²¹³ Greater Vancouver Regional District Air Quality Management Bylaw No. 1082, 2008.
http://www.metrovancouver.org/boards/bylaws/Bylaws/RD_Bylaw_1082.pdf

²¹⁴ Greater Vancouver Regional Solid Waste Management Plan. July, 1995.

²¹⁵ AECOM. Management of Municipal Solid Waste in Metro Vancouver – A comparative Analysis of Options for Management of Waste After Recycling. June, 2009.

²¹⁶ Air-Tec Consulting Ltd. Metro Vancouver Waste-to-Energy Facility Compliance Testing Report. February 2010 Emission Survey. Feb. 2010.

²¹⁷ Air-Tec Consulting Ltd. GVRD Waste-to-Energy Facility Semi-Volatile Organics Testing Report. 2009 Emission Survey. Unit 3 Stack. November 7, 2009.

Table 9-7: Burnaby Incinerator ELVs and Actual Emissions (2007)

Contaminant	Concentration Units	Burnaby WTE ELV	Burnaby WTE (Actual Emissions) ⁽¹⁾	Averaging Period	Monitoring Technique
Total Particulate Matter (TPM)	mg/Rm ³	20	3.8	Manual stack testing	Primary: EPS 1/RM/8 Method E Supporting: EPA Method 5 ²
Sulphur Dioxide (SO ₂)	mg/Rm ³	200	85	24-hour average and Manual stack testing	Primary: CEMS EPS 1/PG/7 Supporting: EPA Method 6
Hydrogen Chloride (HCl)	mg/Rm ³	55	23.6	Manual stack testing	Primary: EPS 1/RM/1 Supporting: EPA Method 26, BC Method 7176106 and 7066101 ²
Hydrogen Fluoride (HF)	mg/Rm ³	3	0.1	Manual stack testing	Primary: EPS 1/RM/1 Supporting: EPA Method 26, BC Method 7176106 and 7066101 ²
Nitrogen Oxides (NO _x) (as NO ₂)	mg/Rm ³	350	265	24-hour average	CEMS: EPS 1/PG/7
Carbon Monoxide (CO)	mg/Rm ³	55	23	4-hour rolling average	CEMS: EPS 1/PG/7
Cadmium (Cd)	µg/Rm ³	100	0.6	Manual stack testing	Primary: EPA Method 29 ²
Lead (Pb)	µg/Rm ³	50	5.9		
Mercury (Hg)	µg/Rm ³	200	2		
Cd + Hg + Tl	µg/Rm ³	200	2		
Sum (As, Co, Ni, Se, Te)	µg/Rm ³	1000	8		
Sum (Sb, Pb, Cr, Cu, Mn, V, Zn)	µg/Rm ³	5000	69		
Total Hydrocarbons (as CH ₄)	mg/m ³	40	4.3	Manual stack testing	Primary: EPA Method 18 ²
PCDD/F TEQ (Dioxins and Furans)	ng/Rm ³	0.5	0.002	Manual stack testing	Primary: EPS 1/RM/2, 1/RM/3, 1/RM/23 Supporting: EPA Method 23 ³
PAH	µg/Rm ³	5	0.13	N/A	Primary: EPS 1/RM/2, 1/RM/3, 1/RM/23 Supporting: EPA Method 23 ³
Opacity	%	5	0.5	1-hour	EPS 1/PG/7

NOTES:

All contaminant concentrations are stated at standard conditions of 293 K, 101.3 kPa, corrected to 11% O₂ and dry basis unless otherwise noted.

¹ Actual Emissions for the Burnaby incinerator were extracted from the AECOM (June, 2009) report.

² Air-Tec Consulting Ltd. Metro Vancouver Waste-to-Energy Facility Compliance Testing Report. February 2010 Emission Survey. Feb. 2010.

³ Air-Tec Consulting Ltd. GVRD Waste-to-Energy Facility Semi-Volatile Organics Testing Report. 2009 Emission Survey. Unit 3 Stack. November 7, 2009.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 9: Emission Limits and Their Application

In general, the Burnaby incinerator permit requirements are in agreement with the provincial 1991 emissions criteria for MSW combustion (Table 8-2). The exceptions include permit limits SO₂ and HCl contaminants which are more stringent than the provincial criteria. Also, under the Burnaby permit the long-term monitoring requirements for HF call for manual stack testing, whereas provincial criteria require continuous monitoring and 8-hr rolling averaging.

Since the 1995 objectives have been met, Metro Vancouver has been working on revising the 1995 provincially mandated plan. The draft Integrated Solid Waste and Resource Management (ISWRM) report^[218] was released in November, 2009. The new target of the ISWRMP increases the regional diversion rate from an average of 55% to 70% by 2015. The plan also identifies aggressive waste reduction strategies to recover materials and energy from remaining waste through four goals:

Goal 1: Minimize waste generated

Goal 2: Maximize reuse, recycling and material recovery

Goal 3: Recover energy from the waste stream after material recycling

Goal 4: Dispose of all remaining waste in landfill, after material recycling and energy recovery.

The strategies identified to achieve the ISWRMP target under Goal 3 include:

- Use of WTE to provide electricity and district heating
- Recover energy from other solid waste management facilities
- Utilize non-recyclable material as fuel.

This includes the ongoing use of the Burnaby Incinerator as one of the approved disposal facilities, expansion of WTE utilization in the region (up to 500,000 tonnes per year of new WTE capacity), and development of new WTE capacity through new projects designed to maximize the environmental, financial, and social benefits.

9.1.3.3 Proposed Gold River Power (formerly Green Island) WTE Facility

The Gold River Power facility proposed by Covanta, will be capable of converting approximately 750,000 tonnes of post-recycled municipal solid waste per year to clean energy. This thermal power plant is proposed to be located at the former pulp mill site in Gold River, BC.

The proposed facility has an existing permit PA-17426, issued May 13, 2004 (last amended November 25, 2005), which authorizes the discharge of air emissions from a wood-fueled power boiler (Phase I Boiler) and a refuse derived fueled (RDF) modified recovery boiler (Phase II Boiler). Table 9-8 presents the ELVs identified in the existing permit for this facility.

²¹⁸ Integrated Solid Waste and Resource Management: A Draft Solid Waste Management Plan for the Greater Vancouver Regional District and Member Municipalities. November, 2009.

However, design of the facility (as well as ownership) has shifted to a design involving two new state-of-the-art boilers (No.1 and No. 2), each with independent Air Pollution Control (APC) equipment, and an application has been recently submitted to amend the existing air permit accordingly.

Combustion controls are proposed to maintain low levels of carbon monoxide and minimize products of incomplete combustion. Covanta's proprietary Very Low NO_x VLN™ system (patent pending) and a Selective Non-Catalytic Reduction (SNCR) system are proposed to achieve NO_x emissions levels that meet Provincial NO_x control criteria. The proposed APC approach would also include a scrubber, baghouse, carbon injection system and a continuous emission monitoring system. Lime injection and temperature control at the scrubber will control acid gases and carbon injection before the scrubber is intended to provide mercury and dioxin control.

The following table compares the authorized emissions from Phase I and Phase II Boilers under the existing permit with the proposed authorized emissions from the new high-efficiency boilers.

Table 9-8: Proposed Green Island Energy Emission Limit Values

Parameter	EXISTING Phase I Boiler (wood fueled)	EXISTING Phase II Boiler (RDF fueled)	PROPOSED Boilers Nos. 1 and 2
Max. Authorized Rate of Discharge	147 m ³ /s	220 m ³ /s	220 m ³ /s
Authorized Discharge Period	Continuous	Continuous	Continuous
Total Particulate Matter (1)	15 mg/m ³	15 mg/m ³	9.0 mg/m ³
Particulate matter less than 10 µm in diameter (PM ₁₀) (2)	No limit stipulated	No limit stipulated	23.0 mg/m ³
Particulate Matter less than 2.5 µm in diameter (PM _{2.5}) (2)	No limit stipulated	No limit stipulated	22.0 mg/m ³
Opacity	5%	5%	5%
Flue gas temperature (3)	No limit stipulated	190C	190C
Carbon Monoxide (CO)	No limit stipulated	110.0 mg/m ³ (4)	83.0 mg/m ³
Hydrogen Chloride (HCl)	No limit stipulated	70.0 mg/m ³	27.5 mg/m ³ (1hr) 23.8 mg/m ³ (24hr)
Hydrogen Fluoride (HF)	No limit stipulated	3.0 mg/m ³	1.8 mg/m ³ (1hr) 0.9 mg/m ³ (24hr)
Sulphur Dioxide (SO ₂)	No limit stipulated	200.0 mg/m ³ (5)	50.0 mg/m ³
Nitrogen Oxides (NO _x)	No limit stipulated	No limit stipulated	150.0 mg/m ³ (1hr) 123.0 mg/m ³ (24hr)
Total Hydrocarbons as CH ₄	No limit stipulated	40.0 mg/m ³	4.8 mg/m ³
Dioxins and Furans (I-TEQ)	No limit stipulated	8.0E-08 mg/m ³	8.14E-08 mg/m ³ (6)
Total Mercury (Hg)	No limit stipulated	0.02 mg/m ³	0.02 mg/m ³
Class I metals (Total of Cd, Hg, Tl)	No limit stipulated	0.2 mg/m ³	Note 7
Class II metals (Total of As, Co, Ni, Se, Te)	No limit stipulated	1.0 mg/m ³	Note 7

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 9: Emission Limits and Their Application

Parameter	EXISTING Phase I Boiler (wood fueled)	EXISTING Phase II Boiler (RDF fueled)	PROPOSED Boilers Nos. 1 and 2
Class III metals (Total of Sb, Pb, Cr, Cu, Mn, V, Zn)	No limit stipulated	5.0 mg/m ³	Note 7
Polychlorinated biphenyls (PCBs)	No limit stipulated	No limit stipulated	0.0005 mg/m ³ ⁽⁸⁾
Chlorophenols	No limit stipulated	No limit stipulated	0.0005 mg/m ³ ⁽⁹⁾
Chlorobenzene	No limit stipulated	No limit stipulated	0.0005 mg/m ³ ⁽¹⁰⁾
Lead (Pb)	No limit stipulated	(7)	0.05 mg/m ³
Arsenic (As)	No limit stipulated	(7)	0.004 mg/m ³
Cadmium (Cd)	No limit stipulated	(7)	0.0072 mg/m ³
Chromium (Cr)	No limit stipulated	(7)	0.001 mg/m ³
Poly Aromatic Hydrocarbons (PAH)	No limit stipulated	0.005 mg/m ³	0.0025 mg/m ³ ⁽¹¹⁾

NOTES:

Concentrations are at the following standard conditions: dry gas, 293.15K, 101KPa, 11%O₂

¹ Total particulate matter concentrations referred to in PA-17426 constitute filterable particulate matter as determined by EPA Method 5.

² Includes filterable and condensable particulate matter as determined by US EPA test methods 5 and 202, excluding chlorides and ammonium.

³ Measured after baghouse.

⁴ 4-hour rolling average.

⁵ 24-hour rolling average.

⁶ CCME Standard (corrected to 20°C) is 8.14E-08 mg/m³.

⁷ Concentrations of groups of metals in existing PA-17426 (Class I, II and III) are proposed to be replaced by specific metal concentrations (Hg, Cd, As, Pb, and Cr).

⁸ Includes total of mono, di, tri, tetra penta, hexa, hepta, octa, nona, and deca chlorinated bi-phenols.

⁹ Includes di, tri, tetra, and penta chlorophenol.

¹⁰ Includes di, tri, tetra, penta and hexa chlorobenzene.

¹¹ Includes emissions for acenaphthylene, acenaphthene, fluorine, phenanthrene, anthracene, fluoranthene, pyrene, chrysene, benzo(a)anthracene, benzo(e)pyrene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, perylene, indeno(1,2,3-cd)pyrene, dibenzo(a,h)anthracene, benzo(g,h,i)perylene, and benzo(l)phenanthrene. Excludes naphthalene.

9.1.4 Regulatory Environment in Alberta

There are currently no regulatory requirements specific to WTE facilities in Alberta. At present, release of air contaminants is managed on a case-by-case basis through conditions outlined in permits authorized by Alberta Environment (AENV).^[219] The Enerkem Waste to Ethanol plant in Edmonton was approved on April 21, 2009, under the *Environmental Protection and Enhancement Act*.^[220] As part of its terms and conditions, the permit authorizes air emissions under the following conditions.

²¹⁹ Pers. Comm. Amit Banerjee, Designated Director under the *Environmental Protection and Enhancement Act* (AEnv) and Magda Kingsley, Stantec, February 29, 2010

²²⁰ Alberta Environment. *Environmental Protection and Enhancement Act* R.S.A. 200, c.E-12, as amended. Approval No 249118-00-00. April 21, 2009

- Air monitoring must comply with applicable AENV requirements outlined under:
 - The *Alberta Stack Sampling Code*, Alberta Environment, 1995, as amended
 - The *Methods Manual for Chemical Analysis of Atmospheric Pollutants*, Alberta Environment, 1993, as amended
 - The *Air Monitoring Directive*, Alberta Environment, 1989, as amended.
- Air emissions requirements must comply with the CCME *National Emission Guideline for Commercial/Industrial Boilers and Heaters*^[221] during the construction phase
- Air emissions during the operation phase shall not exceed the limits listed in Table 8-9. It is noteworthy that the emission limits in the permit are in units of kg/hr but with no linkage to emission volume, so a concentration limit is not established directly or indirectly.
- Ongoing monitoring and reporting is required as outlined in the Approval.

Table 9-9: Air Emissions Limits for the Enerkem Facility

Emission Source	Substance	Emissions Limit
Waste Heat Recovery Unit Stack	NO _x (expressed in NO ₂)	10 kg/hr
	SO ₂	1.3 kg/hr
Boiler Stack	NO _x (expressed in NO ₂)	0.9 kg/hr
All baghouse and dust collection systems	PM	0.20 g/kg

In practice, the kg/hr limits are the flow rate of the operation multiplied by the concentration of the contaminants. It is not possible to convert kg/hr emission limits into concentration numbers for comparison elsewhere in this report since the flow rate is not specified in the information Stantec was able to obtain.

9.1.5 Regulatory Environment in Ontario

Currently, the Ontario Ministry of the Environment applies two separate regulatory requirements to address air emissions from thermal treatment facilities: Ontario MOE Guideline A-7 *Air Pollution Control, Design and Operation Guidelines for Municipal Waste Thermal Treatment Facilities* and Ontario Regulation 419/05 with Point of Impingement (POI) guidelines and Ambient Air Quality Criteria (AAQC).

Ontario Guideline A-7 specifies a maximum allowable concentration of the critical contaminants in the exhaust flue gases from municipal waste thermal treatment facilities and is based on the “Maximum Achievable Control Technology (MACT)” principle, which is similar to the approach taken by a number

²²¹ Canadian Council of Ministers of the Environment. National Emission Guideline for Commercial/Industrial Boilers and Heaters. Initiative N306. N 1286. March, 1998

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 9: Emission Limits and Their Application

of other jurisdictions. The MACT standards are based on emission levels already achieved by best-performing similar facilities.^[222]

Ontario Regulation 419/05 POI limits and AAQC are used to assess the potential for causing an adverse effect and general air quality at the WTE facility property line and beyond. These air standards were developed as a result of the well defined scientific evaluation of the likelihood of adverse health effects due to exposure of a human or ecosystem to a physical or a chemical agent. The POI standards are used by the MOE regularly to determine regulatory compliance of a facility and its emission sources for Certificate of Approval (Air) purposes.^[223]

The following subsections describe both Guideline A-7 and Regulation 419/05 in more depth.

9.1.5.1 Ontario Guideline A-7

Ontario MOE Guideline A-7 sets out minimum recommendations for pollution control systems and maximum allowable “in-stack” contaminant emission levels from municipal waste thermal treatment facilities in Ontario. In addition, the Guideline also sets out recommendations for acceptable design and operating parameters. The Guideline applies to all thermal treatment facilities processing municipal waste including manufacturing facilities, if they use MSW as an alternative fuel.

Guideline A-7 is applied through conditions on Certificates of Approval in accordance with the requirements of the *Environmental Protection Act*, Part V, Section 27, and Part II, Section 9. The EPA requires that a proponent of a municipal waste incinerator apply to the Ministry of Environment for approval to install and operate an incinerator. If the application is approved, the Ministry will issue a certificate of approval for the incinerator which will incorporate emission limits, and monitoring and operating requirements, based on the limits and criteria set out in Guideline A-7. The certificate may also incorporate other requirements specific to the location and the nature of the application for approval.

Emissions criteria specified in Guideline A-7 are relatively stringent. The emission limits for mercury and dioxin/furans are identical to the limits set by the Canadian Council of Ministers of the Environment (CCME) – Canada-Wide Standards for Mercury Emissions and Canada-wide Standard for Dioxins and Furans Emissions for MSW incinerators. The emissions limits are generally comparable (some lower and some higher, but within the same order of magnitude) with the current regulations governing such facilities in both the United States and Europe. Emission limits specified in Guideline A-7 are reviewed and updated by the Ministry to reflect technology improvements and new health and environmental information.

Guideline A-7 was most recently updated in October 2010 (after last being updated in 2004). The updates made to the Guideline include a reduction in the emission limits for particulate matter, cadmium, lead, nitrogen oxides, organic matter and also new emission limits for carbon monoxide and opacity from 2004 levels. The reduced emission limits were introduced to reflect requirements in

²²² Ontario Ministry of the Environment. Guideline A-7: Air Pollution Control, Design and Operation Guidelines for Municipal Waste Thermal Treatment Facilities. October 2010.

²²³ Ontario Ministry of the Environment. SUMMARY of O. REG. 419/05 Standards and Point of Impingement Guidelines and Ambient Air Quality Criteria (AAQCs). Standards Development Branch. Ontario Ministry of the Environment. December 2005

other jurisdictions as well as the capacity of current technologies. When draft revisions to the 2004 version of Guideline A-7 were first released in 2009, the Ministry proposed to also reduce the emission limit for dioxins and furans from 80 pg/Rm³ to 32 pg/Rm³. However, after considerable consultation the Ministry decided to keep the 2004 ELV for the following reasons:

- It is already the most stringent in the world;
- It is the same as the Canada Wide Standard Value;
- The CCME reviewed this limit in 2007 and found no reason to revise it; and finally,
- Releases to the environment at the level below 80 pg/Rm³ cannot be accurately measured.

In addition to new emission limits, the new 2010 Guideline also includes special considerations for experimental units, small units in remote locations in northern Ontario, and provides additional guidance on continuous or long-term monitoring requirements as well as handling of data obtained from these systems.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 9: Emission Limits and Their Application

Table 9-10: Emissions Requirements, Ontario Guideline A-7 (2004 and 2010)

Contaminant	Concentration Units	Ontario MOE A-7 OLD (February 2004)	Ontario MOE A-7 CURRENT (October 2010)	Comments
Particulate Matter (PM)	mg/Rm ³ @ 11% O ₂	17	14	Calculated as the arithmetic average of three stack tests conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system (2004). Results from compliance source testing or calculated as the rolling arithmetic average of four (4) hours of data before dilution with any other gaseous stream, measured by a continuous emission monitoring system that provides data at least once every fifteen minutes (2010).
Sulphur Dioxide (SO ₂)	mg/Rm ³ @ 11% O ₂	56	56	Calculated as the arithmetic average of three stack tests conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system. (2004). Results from compliance source testing or calculated as the rolling arithmetic average of 24 hours of data measured by a continuous emission monitoring system that provides data at least once every 15 minutes (2010).
Hydrogen Chloride (HCl)	mg/Rm ³ @ 11% O ₂	27	27	Calculated as the arithmetic average of three stack tests conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system (2004). Results from compliance source testing or calculated as the rolling arithmetic average of 24 hours of data measured by a continuous emission monitoring system that provides data at least once every 15 minutes (2010).
Nitrogen Oxides (NO _x) (as NO ₂)	mg/Rm ³ @ 11% O ₂	207	198	Calculated as the arithmetic average of three stack tests conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system (2004). Results from compliance source testing or calculated as the rolling arithmetic average of 24 hours of data measured by a continuous emission monitoring system that provides data at least once every 15 minutes (2010).
Carbon Monoxide (CO)	mg/Rm ³ @ 11% O ₂	N.Def.	40	Calculated as the rolling arithmetic average of four (4) hours of data at the outlet of the piece of equipment where combustion of the gas stream resulting from thermal treatment of waste is completed but before dilution with any other gaseous stream, measured by a continuous emission monitoring system that provides data at least once every fifteen minutes (2010).

Contaminant	Concentration Units	Ontario MOE A-7 OLD (February 2004)	Ontario MOE A-7 CURRENT (October 2010)	Comments
Cadmium (Cd)	µg/Rm ³ @ 11% O ₂	14	7	Calculated as the arithmetic average of three stack tests conducted in accordance with standard methods (2004). Results from compliance source testing (2010).
Lead (Pb)	µg/Rm ³ @ 11% O ₂	142	60	Calculated as the arithmetic average of three stack tests conducted in accordance with standard methods (2004). Results from compliance source testing (2010).
Mercury (Hg)	µg/Rm ³ @ 11% O ₂	20	20	Calculated as the arithmetic average of three stack tests conducted in accordance with standard methods (2004). Results from compliance source testing or calculated as the rolling arithmetic average of 24 hours of data measured by a continuous emission monitoring system that provides data at least once every 15 minutes (2010).
Cd + Tl	µg/Rm ³ @ 11% O ₂	N.Def.	N.Def.	
Sum (Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V)	µg/Rm ³ @ 11% O ₂	N.Def.	N.Def.	
PCDD/F TEQ (Dioxins and Furans)	ng/Rm ³ @ 11% O ₂	0.08	0.08	Calculated as the arithmetic average of three stack tests conducted in accordance with standard methods (2004). Results from compliance source testing; results expressed as I-TEQ (2010).

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 9: Emission Limits and Their Application

Contaminant	Concentration Units	Ontario MOE A-7 OLD (February 2004)	Ontario MOE A-7 CURRENT (October 2010)	Comments
Organic Matter (as Methane)	mg/Rm ³	65.6	33	Calculated as a 10 minute average at the outlet of the secondary chamber before dilution with any other gaseous stream, measured by a continuous emission monitoring system (2004). Results from compliance source testing or calculated as the rolling arithmetic average of 10 minutes of data at the outlet of the piece of equipment where combustion of the gas stream resulting from thermal treatment of waste is completed but before dilution with any other gaseous stream takes place, measured by a continuous emission monitoring system that provides data at least once every minute (2010).
Opacity		N.Def.	10%	Calculated as the rolling arithmetic average of six (6) minutes of data measured by a continuous emission monitoring system that provides data at least once every minute (2010).
			5%	Calculated as the rolling arithmetic average of two (2) hours of data measured by a continuous emission monitoring system that provides data at least once every fifteen minutes (2010).

NOTES:

Reference flue gas conditions are defined as 25°C, 101.3 kPa. 11% O₂ under dry conditions.

Guideline A-7 requires that within six months of an incineration facility starting up, stack emissions test results be submitted to the MOE to ensure the facility is in compliance with the emissions limits. Source testing must be performed under maximum operating feed and must be completed using the methods and procedures documented in the Ontario Source Testing Code (Procedure A-1-1). After the initial test, additional tests must be completed on an annual basis to ensure compliance. The guidelines also states that a report documenting the results of the test be submitted to the MOE within 90 days of the tests completion and also be made available to the public for review.

Guideline A-7 also outlines the proper design and operations of an incineration facility to ensure that good combustion conditions are met. Specifically the Guideline outlines nine different operational parameters that should be met by an incinerator. Table 8-11 outlines the parameters and what Guideline A-7 requires.

Table 9-11: Guideline A-7: Design and Operation Considerations for Municipal Waste Incinerators

Consideration	Description
Combustion Temperature	<p>The Ministry acknowledges that temperatures in the combustion chamber or zone of municipal waste incinerators and other combustion equipment will vary with the design.</p> <p>A minimum temperature of 1,000°C is considered adequate to ensure high-efficiency combustion and destruction of products from thermal treatment of municipal waste. The equipment that is used, at least in part, to destroy organic compounds, including products of incomplete combustion, and to meet the organic matter and the carbon monoxide limits, shall be capable of sustaining, on a continuous basis, a temperature that is 100°C degrees greater than the minimum required operating temperature. This capability to operate at a temperature of up to 1,100°C is expected to provide an adequate safety margin as the actual operating temperature should always be more than 1,000°C unless an alternative temperature is approved.</p> <p>An auxiliary burner is expected to be incorporated into the design to ensure that the minimum operating temperature is maintained:</p> <ul style="list-style-type: none"> ▪ At start-up before the commencement of the thermal treatment cycle, i.e., Before any waste is fed into the equipment ▪ During shutdown until all thermal treatment of waste has ceased ▪ At all times when waste is being thermally treated.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 9: Emission Limits and Their Application

Consideration	Description
Combustion Gas Residence Time	<p>The Ministry recognizes that there are municipal waste thermal treatment facilities in operation throughout the world with a wide range of combustion gas residence times in the portion of the facility that combusts gases from thermal treatment of waste. A minimum residence time of one second in the combustion zone at the minimum combustion temperature specified in this guideline is anticipated to be sufficient for providing high-efficiency destruction of the chemical species that may be present in the gas stream entering the combustion zone or equipment.</p> <p>It is acknowledged, however, that performance of a combustion system is dependent on the combination of the temperature and the residence time together with equipment design that may affect gas turbulence. Therefore a combustion temperature that is lower than 1,000°C may be acceptable if the residence time is increased accordingly. Additionally, certain combustion equipment used to burn materials/ by-products from thermal treatment may not be designed to achieve the combustion temperature specified in this guideline but its use in selected applications has proven to result in good combustion of the compounds present in those applications. It is the responsibility of the proponent to justify the temperature-residence time combination being proposed for an incineration or other combustion system.</p> <p>The residence time shall be calculated from the point where most of the combustion has been completed and the combustion temperature has fully developed. If air is introduced downstream of the burner flame front, residence time shall be calculated from the final air injection point to the location of the thermocouple that is used to verify combustion temperature. In some cases, such as large mass burn units, overall design review, including temperature profiles, may need to be carried out to determine the portion of the unit that is considered to be the combustion zone for the purposes of residence time calculations.</p> <p>If a proponent is of the opinion that residence time within a certain combustion device is not relevant for compliance with the in-stack contaminant concentration limits, the proponent is expected to provide a detailed rationale for the opinion, preferably with manufacturer's data, relevant test data and information on requirements in other jurisdictions for facilities similar to the one being proposed. An application for a Certificate of Approval for such a facility will be reviewed on a case by case basis.</p>
Combustion Air Distribution	<p>Combustion air systems shall be designed to control air distribution within the thermal treatment equipment and/or the device that combusts gases generated during thermal treatment of municipal waste. Ideally, control systems shall have the capability of adjusting the distribution of combustion air in order to provide adequate mixing of the gases and the desired level of residual oxygen in the exhaust gases under all loading conditions. The Ministry recognizes that these systems vary widely.</p>

Consideration	Description
Oxygen Availability	<p>Lack of sufficient oxygen during combustion of any combustible material, including gases generated during thermal treatment of municipal waste, is a contributing factor to the discharge of products of incomplete combustion. Components of thermal treatment facilities shall be designed and operated to ensure that there is sufficient residual oxygen in the flue gases from the component used for combustion of gases from thermal treatment of waste. Availability of oxygen and ability to control the amount of oxygen are intended to minimize the discharge of products of incomplete combustion at all times when waste is being thermally treated. A sufficient level of residual oxygen in the exhaust gases is critical with respect to meeting the organic matter and carbon monoxide limits set out.</p> <p>Thermal treatment facilities are typically expected to be designed and operated to provide an oxygen rich atmosphere in the combustion zone or dedicated piece of combustion equipment with residual oxygen level of at least 6% by volume on dry basis in the undiluted gases leaving the combustion zone. The Ministry acknowledges that the recommendation of 6% residual oxygen may be too conservative for some designs, such as those where the gases from the solid waste are a product of a carefully controlled gasification process, followed by elaborate cleaning and refining of the gases to the point of the gases becoming a gaseous fuel with consistent quality rather than being a complex mixture of products of incomplete combustion. In order to establish an appropriate oxygen level, there will be a need to balance between energy recovery, emissions of oxides of nitrogen and the system's ability to deal with variations in waste feed quality. The composition of waste can vary significantly depending on factors such as the extent and type of industrial activity, seasonal activities and level of recycling, and so will the gases from the thermal treatment of that waste. It is also noted that a proposal may involve use of "engineered fuel", solid or gaseous, made from municipal waste that meets certain specifications and is therefore expected to be of more consistent quality. In this case, the combustion process may not be subject to great challenges and an oxygen level below 6% may be acceptable.</p>
Gas-Phase Turbulence and Mixing	<p>The design and operation of a thermal treatment facility shall provide a high degree of gas-phase turbulence and mixing in the combustion zone. This can usually be achieved through appropriately located/directed air jets, changes of flue gas flow direction, baffling, and constriction of cross-sectional flue gas flow area.</p>
Range of Operation	<p>Municipal waste thermal treatment facilities shall be designed and operated to achieve the required temperature, residence time, oxygen availability and turbulence over the expected range of operation, taking into account feed rate variations, as well as ultimate analysis, heating value, ash and moisture content of the waste together with combustion air requirements and heat losses.</p>

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 9: Emission Limits and Their Application

Consideration	Description
Continuous Operation of Air Pollution Control Systems	<p>Air pollution control systems for thermal treatment facilities are expected to be designed to operate on a continuous basis whenever there is waste being processed in the thermal treatment facility. The design of the system should consider:</p> <ul style="list-style-type: none">▪ Conditions that could lead to an unscheduled shutdown of the air pollution control system or the entire facility;▪ Means of ameliorating such conditions; and▪ Means for system venting when there is a need to bypass the air pollution control equipment. <p>Control systems at a thermal treatment facility shall be designed to ensure the shutdown of the thermal treatment facility immediately upon an unscheduled shutdown of the air pollution control system in a manner that will minimize air emissions, unless the system allows redirection of flue gases into equipment that operates and provides control that is equivalent to the control provided by the equipment that was shut down.</p> <p>The control system shall also be designed to record pertinent information for subsequent reporting to the Ministry's local district office and for an assessment of the reasons for the shutdown and potential measures to prevent a recurrence.</p>
Pressure Control and Emergency Exhaust	<p>Thermal treatment facilities shall be designed to operate under negative pressure during all phases of operation so that gaseous products from the thermal treatment of waste do not leak out of the thermal treatment facility. The requirement for negative pressure does not apply to equipment that may be designed to operate under pressure. A Certificate of Approval issued for the thermal treatment facility will include conditions relating to abnormal operating conditions, shut down and cessation of waste feed during abnormal operating conditions as well as use of the emergency exhaust.</p>

Consideration	Description
Ash Management and Organic Content of Ash	<p>Municipal waste thermal treatment facilities typically generate residues that are collected from various parts within the facility. One such residue, often referred to as bottom ash, is typically removed from the chamber, vessel or other equipment into which the municipal waste is introduced. Some designs offer a capability to vitrify (solidify into a glass-like substance) this residue. Residue can also be collected from equipment used for energy recovery from gases from thermal treatment and from air pollution control equipment (fly ash). Owners and operators of thermal treatment facilities are encouraged to consider beneficial use of any residues where possible.</p> <p>Under Regulation 347, fly ash from an incinerator's energy recovery and pollution control system must be handled separately from the bottom ash generated in the zone where municipal waste is incinerated. Similarly, for other types of thermal treatment facilities, the fly ash should be kept separate from the bottom ash or any other residue.</p> <p>Thermal treatment facility operators are expected to test the ash and other residues in accordance with the conditions included in a Certificate of Approval issued under Part V of the EPA (waste approval) before the ashes and/ or residues are transferred from the site of the thermal treatment facility.</p> <p>Testing of bottom ash involves determination of organic content in all cases to confirm that it meets the definition of incinerator ash set out in Regulation 347. The organic content in ash should be determined using Loss on Ignition testing on dry ash samples with ferrous metals absent or as otherwise required by conditions included in a Certificate of Approval. Owners and operators of municipal waste thermal treatment facilities are expected to develop a detailed protocol for sampling and analysis of residues that are to be tested. The protocol is expected to be periodically reviewed and amended as experience with the facility is gained and test results are available. The operation of a thermal treatment facility is expected to be controlled such that the organic content of the bottom ash is minimized to the greatest degree possible.</p> <p>In accordance with Regulation 347 incinerator ash (bottom ash), as defined, resulting from the incineration of waste that is neither hazardous waste nor liquid industrial waste is not a hazardous waste and may be disposed of at a site that is approved to receive solid non-hazardous waste. Owners and operators of thermal treatment facilities processing municipal waste are not required to carry out Toxicity Characteristic</p> <p>Leachate Procedure (TCLP) on the bottom ash that meets the definition of incinerator ash (i.e., has an organic content of less than 10%). Testing using TCLP, however, is required if the organic content exceeds 10% unless the bottom ash is to be disposed of at a waste disposal site approved to accept hazardous waste. In the absence of testing, the owners and operators must assume that the bottom ash is hazardous waste and handle it accordingly.</p> <p>Fly ash from thermal treatment of municipal waste, on the other hand, is assumed to be hazardous waste unless otherwise proven. Therefore, if an operator of a thermal treatment facility wishes to classify the fly ash, or any other residue aside from bottom ash, as non-hazardous, the ash or other residue must be tested to determine if it is leachate toxic. The Ministry's testing protocol, TCLP, is referenced in Regulation 347 while the sampling procedure and results evaluation procedure is in the Ministry's publication "Protocol for Sampling and Evaluating Fly Ash from Non-Hazardous Solid Waste Incineration Facilities" October 1990 as may be amended.</p>

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 9: Emission Limits and Their Application

The Ontario MOE also encourages the installation of Continuous Emissions Monitoring Systems for the following parameters:

- Temperature
- Organic matter
- Carbon monoxide
- Residual oxygen
- Volumetric flow rate of the flue gas
- Hydrogen chloride
- Sulphur dioxide
- Nitrogen oxides
- Opacity
- Particulate matter.

Other parameters that may also be considered for continuous or long-term monitoring include:

- Carbon dioxide
- Hydrogen fluoride
- Mercury
- Dioxins and furans.

9.1.5.2 O. Reg. 419 Schedule 3 Standards

The MOE Standards Development Branch released a revised version of the *Summary of O. Reg. 419/05 Standards and Point of Impingement Guidelines (POI) and Ambient Air Quality Criteria (AAQCs)* in December 2005.

The regulation incorporates “effects-based” standards derived from AAQC with the appropriate averaging period (e.g., 24 hr, 1 hr, 10 minutes) to enable a more realistic assessment of environmental impacts. The “effect-based” standards are set to protect the most sensitive population, such as children and the elderly, recognizing that some contaminants move through the natural environment, persist for long period of time and/or accumulate in the food chain. Simultaneous exposure through more than one environmental pathway (air, water, food) is also taken into consideration. The effects considered may be based on health, odour, vegetation, soiling, visibility, corrosion or other effects.

The “effects-based” air standards, applicable to the new MSW thermal treatment facilities, are listed in Schedule 3 of the Regulation 419/05. Most of these 24-hour air standards are the same as the AAQCs values in the 2001 MOE document “*Summary of Point of Impingement Standards, Point of Impingement Guidelines, and Ambient Air Quality Criteria (AAQCs)*”. Therefore, the Schedule 3 Standards should be considered the ambient air quality objective set to avoid adverse health effects and to protect the ecosystem. For contaminants that are not listed in Schedule 3 of the Regulation, but are instead listed as a half-hour POI guideline or an AAQC, the exceedance of a POI guideline or of an AAQC is considered to cause the adverse effects.

All contaminants for which there has been a stack emission limit set out in Guideline A-7 (except dioxins and furans) have 24-hour average health-based Schedule 3 standards based on the most recent AAQCs developed via the Ministry's standard setting process. The AAQCs identify the limit for concentration in the air of the specific contaminants that would be emitted from an EFW stack, below which they would not be expected to cause any adverse effects. The AAQCs would be determined for a defined point or points set at a defined distance from a facility (usually between the facility and sensitive community receptors) at which the specific limit for air pollutants must be met.

For dioxins and furans, since there is no Schedule 3 standard, the 24-hour average concentration listed in the AAQC is used. The applicable POI Limits and AAQC for the contaminants that are also regulated by Guideline A-7, are summarized in Table 9-12.^[224]

Table 9-12: O. Reg. 419 Schedule 3 Standards and Ambient Air Quality Criteria (2005)

Contaminant	Concentration Units	MOE Reg. 419 Schedule 3 Standards (24-Hour Average)	MOE AAQC (24-Hour Average)
Total Particulate Matter (TPM)	µg/m ³	120	–
Sulphur Dioxide (SO ₂)	µg/m ³	275	–
Hydrogen Chloride (HCl)	µg/m ³	20	–
Nitrogen Oxides (NO _x) (as NO ₂)	µg/m ³	200	–
Carbon Monoxide (CO)	–	N. Def.	–
Cadmium (Cd)	µg/m ³	2	–
Lead (Pb)	µg/m ³	2	–
Mercury (Hg)	µg/m ³	2	–
PCDD/F TEQ (Dioxins and Furans)	pg TEQ/m ³	–	5

NOTES:

N. Def. = Not Defined

9.1.6 United States Environmental Protection Agency

In the United States, as of 2007, there were 87 WTE facilities operating in 25 states with an approximate capacity of 28.7 million tons per year.^[225] WTE facilities in the United States are regulated by the United States Environmental Protection Agency (US EPA). The US EPA has developed clear and relatively strict limits on the acceptable levels of emissions for many substances from WTE facilities. The emission guidelines are not directly enforceable by the US EPA but, rather, are implemented by State air pollution control agencies. In December 2005, the EPA adopted emission guidelines for large WTE units with a combustion capacity greater than 250 tons per day (sub part Cb of 40 CFR part 60). These adoptions became a final ruling on May 10, 2006. The emissions limitations apply to new MWC units and existing MWC units (compliance was required by December 2000).^[226]

²²⁴ MacViro Consultants and Jacques Whitford Limited. Durham/York Residual Waste Study Annex E-6: Supporting Technical Document on Generic Air Dispersion Modelling Report on Selection of Preferred Residuals Processing System\May 30, 2006

²²⁵ The 2007 IWSA Directory of Waste-to-Energy Plants. Ted Michaels. 2007

²²⁶ Environmental Protection Agency. 2006. 40 CFR Part 60 – Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Large Municipal Waste Combustors; Final Rule

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 9: Emission Limits and Their Application

The emissions limitations set out in the emissions guidelines reflect the performance of maximum achievable control technology (MACT). The MACT standards require affected sources to meet specific emissions limits that are based on the emissions levels already achieved by the best-performing similar facilities. For existing facilities, the MACT is set based upon the best-performing 12% of similar facilities, for new sources, the MACT must equal the level of emissions currently achieved by the best-controlled similar source.^[227]

Table 9-13 summarizes the currently adopted emission limits for new and existing municipal waste combustors. In all cases the emission limits below are checked for compliance using manual stack test methods (where one stack sampling survey result is the average of three individual sample runs).

Table 9-13: US EPA Emissions Criteria for New and Existing Municipal Waste Combustors

Contaminant	Concentration Units	Large MWC ^{1, 2}	
		Existing Facilities	New Facilities
Total Particulate Matter (TPM)	mg/Rm ³ @ 11% O ₂	17.5	14.0
Sulphur Dioxide (SO ₂)	mg/Rm ³ @ 11% O ₂	53.2 ⁴	55.0 ³
Hydrogen Chloride (HCl)	mg/Rm ³ @ 11% O ₂	30.3 ⁵	26.1 ⁵
Nitrogen Oxides (NO _x) (as NO ₂)	mg/Rm ³ @ 11% O ₂	237 to no limit ⁷	197.5 ⁶
Carbon Monoxide (CO)	–	40 to 200 ⁸	41 to 200 ⁸
Cadmium (Cd)	µg/Rm ³ @ 11% O ₂	24.5	7.0
Lead (Pb)	µg/Rm ³ @ 11% O ₂	280.1	98.0
Mercury (Hg)	µg/Rm ³ @ 11% O ₂	35.0	35.0
PCDD/F (Dioxins and Furans)	ng (total mass basis) @ 11% O ₂	21.0 ⁹	9.1 ⁹
Opacity	%	10	10

NOTES:

N. Def. = Not Defined

All emission limits are measured at 11% O₂, 25°C and 101.3 kPa

¹ Large MWC unit has a capacity greater than 250 tons/d

² Units have been converted to Ontario MoE A-7 concentration units to allow direct comparison

³ or 80% reduction by weight or volume of potential SO₂ emissions, whichever is less stringent

⁴ or 75% reduction by weight or volume of potential SO₂ emissions, whichever is less stringent

⁵ or 95% reduction of potential HCl emissions by weight, whichever is less stringent

⁶ 180 ppmdv @ 7% O₂ for 1st year of operation, 150 ppmdv @ 7% O₂ after 1st year of operation

⁷ NO_x limit varies by combustor type: 210 ppmdv @ 7% O₂ for Mass Burn Rotary Waterwall, 180 ppmdv @ 7% O₂ for Fluidized Bed, 205 ppmdv @ 7% O₂ for Mass Burn Waterwall, 250 ppmdv @ 7% O₂ for Refuse-derived fuel, no limit for Mass Burn Refractory (after Apr. 28, 2009)

⁸ CO limit varies per technology: 40 mg/Rm³ @ 11% O₂ for Modular Starved-Air and Excess Air Unit; 200 mg/Rm³ @ 11% O₂ for Spreader Stoker Refuse-derived fuel

⁹ Limit not comparable to Canadian and European limits. Dioxins/furans on total mass basis measured as tetra- through octachlorinated dibenzo-p-dioxins and dibenzofurans. Not TEQ values

²²⁷ The University of Tennessee. 2009. EPA MACT Rules. Accessed March 12, 2010 from <http://epamact.utk.edu/>

It should be noted the EPA has released draft standards for emissions from commercial and industrial solid waste incineration units in April 2010^[228]. These standards are currently in the public domain for comment; it is too early to determine if they will be adopted as presented. Key features of the standards include the provision for continuous monitoring of total particulate, a reduction in the allowable concentration of particulate in the discharge and variability in the allowable concentration depending of the type of incineration facility. Detailed examination of the proposed standards was not possible under our schedule of this WTE Emissions assignment for BC MOE.

9.1.7 Regulatory Environment in the State of Oregon

Oregon Department of Environmental Quality established emission standards, design requirements and performance standards for all solid waste incinerators in order to minimize air contaminant emissions and provide adequate protection of public health as filed through April 15, 2010. Incinerator Regulations are summarized under the Oregon Administrative Rule (OAR) 340-230.^[229] Air emissions from municipal waste combustors with a combustion capacity greater than 250 tons/day must meet the criteria outlined in Table 9-14 (OAR 340-230-300 through 340-230-0395). In addition, no owner or operator of the municipal waste combustor may cause or allow visible emissions of combustion ash from an ash conveying system in excess of 5% of the observed period.

Table 9-14: Oregon Administrative Rule 340-230-310 Incinerator Regulations – Emissions Limits (April 15, 2010)

Contaminant	Units	Before April 28, 2009	On or After April 28, 2009
Particulate Matter (PM)	mg/Rm ³ @ 11% O ₂	19	18
Sulphur Dioxide (SO ₂)	mg/Rm ³ @ 11% O ₂	53 ¹	
Hydrogen Chloride (HCl)	mg/Rm ³ @ 11% O ₂	30 ²	
Nitrogen Oxides (NO _x) (as NO ₂)	mg/Rm ³ @ 11% O ₂	270	
Carbon Monoxide (CO)	–	N. Def.	
Cadmium (Cd)	µg/m ³ @ 11% O ₂	28	14
Lead (Pb)	µg/m ³ @ 11% O ₂	308	140

²²⁸ Environmental Protection Agency 40 CFR Part 60 [EPA-HQ-OAR-2003-0119; FRL-RIN 2060-A012], Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Commercial and Industrial Solid Waste Incineration Units.

²²⁹ Oregon Administrative Rules. Department of Environmental Quality. OAR 340-230. Incinerator Regulations. Filed through April 15, 2010. http://arcweb.sos.state.or.us/rules/OARs_300/OAR_340/340_230.html

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 9: Emission Limits and Their Application

Contaminant	Units	Before April 28, 2009	On or After April 28, 2009
Mercury (Hg)	$\mu\text{g}/\text{m}^3$ @ 11% O ₂	56 ³	35 ³
PCDD/F (Dioxins and Furans)	ng/m^3 @ 11% O ₂	42 ⁴	25 ⁵
Opacity	%	10 ⁶	

NOTES:

N. Def. = Not Defined

All emission limits are converted to 11% O₂, 25°C and 101.3 kPa

¹ Or 25% of the potential SO₂ emission concentration (75% reduction by weight or volume), whichever is less stringent.

² Or 5% of the potential HCl emission concentration (95% reduction by weight or volume), whichever is less stringent.

³ Or 15% of the potential mercury emission concentration (85% reduction by weight), whichever is less stringent.

⁴ Total mass. Applies to municipal waste combustor units that employ electrostatic precipitator-based emission control system. If electrostatic precipitator-based emission controls are not employed, 30 ng per dry m³ (total mass) @ 7% O₂.

⁵ Total mass. Applies to municipal waste combustor units that employ electrostatic precipitator-based emission control system. If electrostatic precipitator-based emission controls are not employed, 15 ng per dry m³ (total mass) @ 7% O₂.

⁶ Opacity considered over a 6-minute average.

9.1.8 Regulatory Environment in the State of Washington

Within Washington State, standards for Energy Recovery and Incineration Facilities are defined under Washington Administrative Code (WAC) 173-350-240 effective 2003.^[230] These standards apply to incineration facilities designed to burn more than 12 tons/day of solid waste or RDF. Although there are no specific design standards, the facilities must meet the general performance requirements under WAC 173-350-040.^[231] The standards require facilities meet emission standards or ambient air quality standards at the property boundary in compliance with chapter 70.94 RCW (Revised Code of Washington), *Washington Clean Air Act*.^[232]

Emission standards, design requirements, and performance standards for solid waste incinerator facilities with a capacity of 12 tons/day or more are defined under WAC 173-434^[233] as promulgated under chapter 70.94 RCW. Table 9-15 summarizes the emission standards applicable to solid waste incinerator facilities. Design and operational requirements are summarized in Table 9-16.

Special emission standard provisions exist for combustor and incinerator units constructed prior to 1999 under WAC 173-400-050.^[234] These emissions standards are less stringent than the criteria summarized in Table 9-15.

²³⁰ Washington Administrative Code. Energy Recovery and Incineration Facilities, WAC 173-350-240.
<http://apps.leg.wa.gov/wac/default.aspx?cite=173-350-240>

²³¹ Washington Administrative Code. Performance Standards, WAC 173-350-040
<http://apps.leg.wa.gov/wac/default.aspx?cite=173-350-040>

²³² Revised Code of Washington. *Washington Clean Air Act*. Chapter 70.94 RCW.

²³³ Washington Administrative Code. Solid Waste Incinerator Facilities, WAC 173-434. <http://apps.leg.wa.gov/wac/default.aspx?cite=173-434>

²³⁴ Washington Administrative Code. Emission Standards for Combustion and Incineration Units, WAC 173-400-050
<http://apps.leg.wa.gov/WAC/default.aspx?cite=173-400-050>

Table 9-15: WAC 173-434-130 Emission Standards for Solid Waste Incinerator Facilities (2003)

Contaminant	Units	Small Facilities ¹	Large Facilities ²
Particulate Matter (PM)	mg/m ³ @ 11% O ₂	48	32
Sulphur Dioxide (SO ₂)	mg/m ³ @ 11% O ₂	92	
Hydrogen Chloride (HCl)	mg/m ³ @ 11% O ₂	52	
Opacity	%	5	

NOTES:

Units have been converted to 11%O₂ and 25°C to allow direct comparison

¹ Small facilities have a capacity less than 250 tons/day

² Large facilities have a capacity equal to or greater than 250 tons/day

³ For an hourly average

⁴ Except if uncontrolled emissions of SO₂ are reduced by at least 80% and a procedure acceptable to ecology or the authority for monitoring is developed

⁵ Except if uncontrolled emissions of HCl are reduced by at least 80% and a procedure acceptable to ecology or the authority for monitoring is developed

⁶ Opacity considered over a 6-minute average in any 6-minute period

Table 9-16: WAC 173-434-160 Design and Operation Requirements for Solid Waste Incinerator Facilities

Consideration	Description
Combustion	
Combustion zone temperature	Whenever solid waste is being burned, the temperature of the final combustion zone shall not be below 982°C (1,800°F) for a fifteen minute average or below 871°C (1,600°F) for any reading.
Combustion zone residence time	The minimum combustion chamber temperature must be maintained for at least one second (1.0 second) in a zone after the last over fire air has entered the combustion chamber. If over fire air is not used, the combustion chamber shall maintain the minimum combustion temperature or greater for at least one second with all combustion gases. Procedures for determining the residence time shall be a part of the new source review.
Excess air	The combustion gases leaving the final combustion zone must contain at least three percent oxygen measured on a wet basis.
Combustion air distribution and control	The air distribution shall be fully controllable where pressurized air is introduced and the air flow shall be monitored and recorded.
Combustion Air	
Combustion air	To minimize odour, fugitive emissions and to maintain a negative pressure in the tipping area, the combustion air shall be withdrawn from the tipping area, or shall utilize an equivalent means of odour and fugitive emission control acceptable to ecology or the authority.
Particulate Control Device Temperature	
Particle control device temperature	The inlet temperature of the primary particulate control device shall not exceed 177°C (350°F).

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 9: Emission Limits and Their Application

Consideration	Description
Operation	
Operation	At all times, the owner or operator shall, to the extent practicable, maintain and operate any incinerator facility, including associated air pollution control equipment, in a manner consistent with good air pollution control practice. This may mean that if the emissions limits are being exceeded, no more waste should be fed into the incinerator until the problem is corrected. Determination of whether acceptable operating and maintenance procedures are being used will be based on information available to ecology or the authority which may include, but is not limited to, monitoring and recording results, opacity observations, review of operating and maintenance procedures, and inspection of the source.

9.1.9 European Union

Within the European Union, there are two directives that regulate the emissions from WTE facilities, namely:

- The Waste Incineration Directive (Directive 2000/76/EC)
- The Integrated Pollution Prevention and Control (IPPC) Directive (Directive 2008/1/EC).

The 2008 version of the IPPC Directive is a codified and slightly changed version of the original IPPC Directive (96/61/EC). Codification refers to the adoption of a directive such as the IPPC directive, into general law within the EU member states. Essentially, most of the provisions of the IPPC have been transposed into the laws put into force within the member states and were put into force many years ago. Both the WID and IPPC directives are addressed to the member states which are given a certain lead time to transpose them into their national legislation. The following sections describe each directive in more detail.

9.1.9.1 The Waste Incineration Directive (WID)

The Waste Incineration Directive (WID) was agreed to by the European Parliament and the Council of the European Union on December 4, 2000 and was officially published in the Journal of European Communities on December 28, 2000. The purpose of the WID is to prevent or limit the negative environmental effects associated with the incineration and co-incineration of waste materials, in particular emissions to air, soil, surface and ground water.

Through the WID, the European aims to “achieve a high level of environmental and human health protection by requiring the setting and maintaining of stringent operational conditions, technical requirements and emission limit values for plants incinerating and co-incinerating waste throughout the European Community.”^[235]

²³⁵ Department for Environment, Food and Rural Affairs. Environmental Permitting Guidance, The Directive on the Incineration of Waste for the Environmental Permitting (England and Wales) Regulations 2007, Updated October 2009

The WID applies to nearly all waste incineration and co-incineration plants. It goes beyond previous legislation such as the 1989 Municipal Waste Incineration (MWI) Directives (89/369/EEC and 89/429/EEC and also incorporates the Hazardous Waste Incineration Directive (94/67/EC) forming a single directive on waste incineration.

Facilities that fall under the directive include any incineration facility dedicated to the thermal treatment of waste including the oxidation of waste or by pyrolysis, gasification, or plasma processes insofar as the substances resulting from the treatment are subsequently incinerated. The WID requires that the local regulation authority ensures that the protection standards and requirements of the WID are met through the Environmental Permitting system.

The WID has specific and stringent requirements for waste incineration and co-incineration facilities including types of waste permitted; delivery and reception of waste; combustion furnaces, abatement facilities, residue handling, monitoring equipment and emission limit values. All requirements are laid out in the permit for the facility issued by the appropriate local authorities.

Proper facility operation is also described in the WID including combustion gas temperatures, flue gas residence times, the TOC content of residues, conditions when waste feed should be stopped, and energy recovery from the plant. It also allows some derogation from these requirements under some conditions.

The WID states that incinerators must be designed, equipped, built and operated such that the flue gas is raised to a temperature of 850°C for two (2) seconds (or in the case of hazardous waste with more than 1% halogenated substances be raised to 1,100°C). The WID also requires that these temperatures be met even under the most unfavourable operating conditions.

Table 9-17 presents some of the emissions limits set out in the Waste Incineration Directive. Generally compliance with these limits would be demonstrated through periodic stack testing, although for some parameters with half hourly emission limit values² compliance would be demonstrated through CEMS.

Table 9-17: Emissions Limits for WTE Facilities Set Out in EU Waste Incineration Directive

Contaminant	Concentration Units	EU Directive 2000/76/EC of the European Parliament and Council on the Incineration of Waste ¹
Total Particulate Matter (TPM)	mg/Rm ³ @ 11% O ₂	9.2 ²
Sulphur Dioxide (SO ₂)	mg/Rm ³ @ 11% O ₂	45.8 ²
Hydrogen Chloride (HCl)	mg/Rm ³ @ 11% O ₂	9.2 ²
Nitrogen Oxides (NO _x) (as NO ₂)	mg/Rm ³ @ 11% O ₂	183.2 ²
Carbon Monoxide (CO)	mg/Rm ³ @ 11% O ₂	45.8 ²
Cadmium (Cd)	µg/Rm ³ @ 11% O ₂	N. Def.
Lead (Pb)	µg/Rm ³ @ 11% O ₂	N. Def.
Mercury (Hg)	µg/Rm ³ @ 11% O ₂	45.8 ³

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 9: Emission Limits and Their Application

Contaminant	Concentration Units	EU Directive 2000/76/EC of the European Parliament and Council on the Incineration of Waste ¹
Cd + Tl	µg/Rm ³ @ 11% O ₂	45.8 ³
Sum (Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V)	µg/Rm ³ @ 11% O ₂	458.1 ³
PCDD/F TEQ (Dioxins and Furans)	ng/Rm ³ @ 11% O ₂	0.092

NOTES:

N. Def. = Not Defined

¹ Units have been converted to Ontario MOE A-7 concentration units to allow direct comparison

² Daily average value by periodic stack test. In addition, the Directive contains half-hourly emission limit values for the same pollutants

³ Average values over the sample period of a minimum of 30-minutes and a maximum of 8 h

9.1.9.2 The Integrated Pollution Prevention and Control (IPPC) Directive

The IPPC Directive is aimed at minimizing the emissions of pollutants from large industrial installations through the use of an environmental permit. Permits contain emission limit values (ELVs) and set conditions based on the application of best available technique (BAT). They also address energy efficiency, waste minimization, prevention of accidental emissions, and site restoration.^[236]

Specifically, the IPPC Directive applies to industrial and agricultural activities with a high pollution potential including energy industries, production and processing of metals, mineral industry, chemical industry, waste management, livestock farming, etc.^[237] For waste incineration plants treating municipal waste (household waste and similar commercial, industrial and institutional wastes) the IPPC directive applies if the facility capacity exceeds three tonnes per hour (72 tonnes per day).^[238]

For WTE facilities that are subject to the IPPC Directive (2008/1/EC), meeting the requirements of the WID Directive are not necessarily sufficient to meet IPPC requirements as they are broader and may involve more stringent emissions limits.

The IPPC Directive is based on several principles, namely: (1) an integrated approach, (2) best available techniques, (3) flexibility; and (4) public participation.

- The integrated approach means that the permits must take into account the whole environmental performance of the plant, covering e.g., emissions to air, water and land, generation of waste, use of raw materials, energy efficiency, noise, prevention of accidents, and restoration of the site upon closure. The purpose of the Directive is to ensure a high level of protection of the environment taken as a whole.

²³⁶ [http://www.eef.org.uk/policy-media/policy-briefs/briefings/Integrated-Pollution-Prevention-Control-\(IPPC\).htm](http://www.eef.org.uk/policy-media/policy-briefs/briefings/Integrated-Pollution-Prevention-Control-(IPPC).htm)

²³⁷ http://europa.eu/legislation_summaries/environment/waste_management/l28045_en.htm

²³⁸ DIRECTIVE 2008/1/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 15 January 2008 concerning integrated pollution prevention and control. January 29, 2008

- The permit conditions including emission limit values (ELVs) must be based on Best Available Techniques (BAT), as defined in the IPPC Directive. To assist the licensing authorities and companies to determine BAT, the Commission organizes an exchange of information between experts from the EU Member States, industry and environmental organizations. This work is coordinated by the European IPPC Bureau of the Institute for Prospective Technological Studies at EU Joint Research Centre in Seville (Spain). This results in the adoption and publication by the Commission of the BAT Reference Documents (commonly referred to as BREFs). Executive summaries of the BREFs are also translated into the official EU languages.
- The BREF on Waste Incineration was issued in August 2006. It contains Chapter 5 – Best Available Techniques with 63 numbered recommendations called BATs. One of these, BAT 35 contains a table with 'operational emission levels for releases to air associated with the use of BAT'. The values in Table 9-18 are, of course, lower than the emission limit values in WID Directive 2000/76, but the BREF states specifically that the BAT emission levels are not the same as emission limit values.
- It is important to stress that the BREF on Waste Incineration does not prescribe the technology to be used at waste to energy facilities nor does the BREF prescribe one technology to be better than the other.

Table 9-18: Comparison of the Requirements of the WID and the BAT Listed in the WI BREF

Contaminant Emissions to Air (mg/Nm ³ unless stated)	WID		BREF/BAT	
	Daily Average ELV	Half Hourly (100%/97% of the time)	Daily Average (operational BAT range)	Half Hour Average (operational BAT range)
Total Particulate	10	30/10	1 – 5	1 – 20
HCl	10	60/10	1 – 8	1 – 50
SO ₂	50	200/50	1 – 40	1 – 150
NO _x (as NO ₂)	<200 to <500 (size/new/existing dependant)	400/200	40 – 100 (SCR) 120 – 180 (SNCR)	40 – 300 (SCR) 30 – 350 (SNCR)
VOC (as Total Organic Carbon)	10	20	1 – 10	1 – 20
CO	50	150 (10 min avg) (some alternatives)	5 – 30	5 – 100
Hg	0.05 (non-continuous sample)		0.001 – 0.02	
Cd/Tl	0.05 (non-continuous sample)		0.005 – 0.05 (non-continuous sample)	
PCDD/F	0.1 ng/m ³ (non-continuous sample)		0.01 – 0.1 ng/m ³ (non-continuous sample)	
Ammonia	Not included in WID		<10	1 – 10
N ₂ O			Information about control techniques is provided	
Benz(a)pyrene				
PAHs				
PCBs				

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 9: Emission Limits and Their Application

The IPPC Directive contains elements of flexibility by allowing the licensing authorities in determining permit conditions, to take into account:

- The technical characteristics of the installation
- Its geographical location
- The local environmental conditions.

The Directive ensures that the public has a right to participate in the decision making process, and to be informed of its consequences, by having access to:

- Permit applications in order to give opinions
- Permits
- Results of the monitoring of releases
- The European Pollutant Emission Register (EPER). In EPER, emission data reported by Member States are made accessible in a public register, which is intended to provide environmental information on major industrial activities. EPER will be replaced by the European Pollutant Release and Transfer Register (E-PRTR) from 2007 reporting period onwards.

9.1.9.3 IED – Industrial Emissions Directive

The European Commission's proposal from December 21, 2007 merges the IPPC directive 96/61/EC, the Waste Incineration directive (WID) 2000/76/EC and some other directives including the Large Combustion Plants Directive 2001/80/EC. This will most likely not occur until 2013.^[239]

The new Directive will include pre-treatment of waste for incineration and for co-incineration as well as treatment of bottom ash and APC ashes. Through the IED, the European Commission aims to strengthen the concept of BAT by making the BREFs more prominent.

One of the problems heavily discussed among the waste to energy sector and the authority, is not to mix-up the emission limit values (ELV) with the BAT AEL (Associated Emission Levels) based on the ranges presented in the BREF and mentioned in the chapter above.

The draft article 16.2 states "the competent authority shall set emission limit values that do not exceed the emission levels associated with the best available techniques as described in the BAT reference document".

The draft article 15.2 says " ...the emission limit values and the equivalent parameters and technical measures ... shall be based on the best available techniques, without prescribing the use of any technique or specific technology."

The time table for the approval of the IED has been delayed and the second reading will go before the European Parliament plenary 18 May 2010.

²³⁹ http://europa.eu/legislation_summaries/environment/waste_management/l28045_en.htm

The review of the BREF on Waste Incineration is expected to take place during the period from 2012 – 2014. It is not yet known if this will result in a general lowering of the ELV or if the IED will result in lowering of the ELV for only some pollutants and discussions are going on among the commission, the national member states and the industry. The general opinion among the member states tends towards keeping the current ELV set out in the WID.

9.1.9.4 European Union Member States Regulatory Limits

Since the EU Directives are addressed to the Member States, countries that are members of the European Union have to transpose the directives. The WID is a 'minimum' directive which means that the Member States are free to set stricter regulatory limits.

In general all European countries, with few exceptions, have implemented the WID and the emission limits. Several have set lower limits as a result of local considerations. Germany and Norway (not an EU member country) have implemented a more stringent emission limit for mercury. For NO_x the Netherlands have specified a limit at 70 mg/Nm³ and Austria and Switzerland (not an EU member country) have specified a limit at 80 mg/Nm³.

Some member states have implemented lower emission values in certain areas, and some individual facilities may have more stringent emission limits in their approvals/permits. An example of how the WID and emissions have been applied in a member state (Germany) is outlined below.

In 2007, Germany had 72 operating WTE facilities that treated waste. Since 1985, waste incineration capacity in Germany has nearly doubled.^[240] Alike to other members of the EU, Germany requires that WTE facilities that operate within its boundaries, meet the emissions standards set out in the EU's Waste Incineration Directive. Germany paved the way for the EU WID. The German Ordinance on Waste Incineration and Co-Incineration (17.BImSchV) which was developed in 1990 set stringent limits on the emissions associated with WTE facilities. The 17.BImSchV sets out the requirements for construction, layout and operation of WTE facilities, and for emissions measurement and monitoring. It outlined a transitional period of six years for existing facilities while new facilities were required to comply with specific limits from the very beginning. Since 1996, all facilities have complied with the stringent emissions requirements.^[241] The limits set out in Germany's 17.BImSchV had a large influence on the emissions limits developed in the EU's WID (2000/76/EC).

In 2003, the 17.BImSchV was updated to incorporate the requirements outlined in the EU WID. Moreover, it contains emission limit values for some additional compounds and it also requires that Hg emissions be monitored continuously. The 17.BImSchV incorporates all the requirements outlined in the EU WID and must be adhered to by all operators of waste incineration facilities.^[242]

²⁴⁰ Germany Federal Environmental Agency, 2005

²⁴¹ Waste Incineration – A Potential Danger? Bidding Farewell to Dioxin Spouting. Federal Ministry of the Environment, Nature Conservation and Nuclear Safety, September 2005

²⁴² Ordinance on Waste Incineration and Co-Incineration – 17. BImSchV. August 2003

It should be noted that CEMS for mercury is an emerging approach for mercury emissions monitoring. As noted above, it is required in Germany. The new CISWI rules proposed in the US include proposed requirements for using Hg CEMS (performance specification 12A – Specifications and Test Procedures for Total Vapor Phase Mercury Continuous Emission Monitoring Systems in Stationary Sources) or an integrated sorbent trap Hg monitoring system.

9.2 Emission Limits for Criteria Air Contaminants and Hazardous Air Pollutants

This subsection identifies and evaluates regulatory emission limits for all air contaminants applicable to WTE scenarios. Table 9-19, provides a comparison of the maximum allowable concentration of various pollutants measured in the discharge under:

- CCME
- British Columbia Criteria for Municipal Solid Waste Incinerators (1991)
- Old Ontario MOE Guideline A-7 (2004)
- New Ontario MOE Guideline A-7 (2010)
- Oregon Incinerator Regulations (OAC 340-230-310)
- Washington Emission Standards for Combustion and Incineration Units (WAC 173-434-130)
- US EPA New Incinerator Limits (i.e., the current US National Standard)
- The European Union, New Incinerator Unit, Regulation (i.e., the current European Standard).

The US EPA and EU limits have been converted to equivalent units comparable to those set out in the CCME and Ontario guidelines. These differ slightly in regards to reference conditions, where the values identified reflect mass per reference cubic metres corrected to 11% oxygen and 0% moisture. Reference conditions: 25°C, 101.3 kPa, except for British Columbia which is based on 20°C.

The emission limits provided are actual values with inherent consideration of achievability. These limits are consistent with BC's Interim BAT policy.

The maximum allowable concentrations, otherwise known as maximum emissions limits values (ELVs) for various jurisdictions are linked to appropriate averaging periods and monitoring methodologies. The limits presented in Table 9-19 are checked for compliance with the methods deemed appropriate by the individual jurisdictions either based on manual stack testing or CEMS data depending on the parameter and applicable averaging periods. Table 9-19 makes note of the applicable averaging periods.

As discussed in Section 7, Table 9-20 illustrates the direct connection between the stated ELVs and the monitoring methodology. Specifically, where continuous emission monitoring instrumentation is considered to be representative of emission quality, the ELV is commonly linked to an average concentration calculated over some specified monitoring period. The ELV is also set considering normal fluctuations in operating conditions that may affect emission quality, and must be set such that the ELV is protective of human health and the environment in all cases. CEMs produce a significant

volume of data and permit the application of statistical methodologies in determining the appropriate ELV for any given parameter. Most commonly, simple averaging techniques are used, such as one half hour average or daily average. These are reflected for certain parameters in Table 9-20.

Where periodic 'stack' testing is conducted as the representative method for obtaining compliance data, the results are typically averaged over the number of replicate sample runs completed during the test. ELVs that are based on a single stack survey made up of three individual sampling runs. An average can be inferred; however, as it is common for replicate tests on larger stacks to take a day or more, and an average over the duration of the test can be calculated. Table 9-20 also indicates where periodic tests form the basis for the ELV.

Monitoring technology is always evolving and consideration should be given to new and innovative monitoring techniques where it can be shown these techniques are reliable and representative of emission quality. Where CEMs can be shown to be equivalent to a periodic monitoring in terms of quality of data, most regulatory agencies are specifying the CEMs could form the basis for the monitoring program. The EPA protocol, SP-11, provides the guidance for demonstrating equivalence between periodic stack sampling results and CEMS results.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 9: Emission Limits and Their Application

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Table 9-19: Comparison of Maximum Allowable Concentration of Pollutants Defined by CCME, BC, Ontario, US, and Europe

Contaminant	Concentration Units	Canadian Council of Ministers of the Environment (CCME) Guidelines (1989)	BC	OLD ONTARIO	OREGON	WASHINGTON	NEW ONTARIO	US EPA 40 CFR Part 60 (May-10-06 Edition) Standards of Performance for Large Municipal Waste Combustors (New Facilities) ^(5,6)	EU Directive 2000/76/EC of the European Parliament And Council on the incineration of waste ⁽⁶⁾
			Emissions Criteria for Municipal Solid Waste Incinerators (1991)	MOE A-7 (February 2004)	OAR 340-230-310 Incinerator Regulations – Emissions Limits for New Facilities (April, 2010)	WAC 173-434-130 Emission Standards for Large Combustion and Incineration Units (2003)	Guideline A-7 (October 2010)		
Total Particulate Matter (TPM)	mg/Rm ³ @ 11% O ₂	20 ⁽¹⁾	20	17	18	32	14	14.0	9.22 ⁽¹²⁾
Sulphur Dioxide (SO ₂)	mg/Rm ³ @ 11% O ₂	260 ⁽²⁾	250	56	53 ⁽¹⁷⁾	92 ⁽²²⁾	56	55.0 ⁽⁷⁾	45.82 ⁽¹²⁾
Hydrogen Chloride (HCl)	mg/Rm ³ @ 11% O ₂	75 or 90% removal ⁽¹⁾	70	27	30 ⁽¹⁸⁾	52 ⁽²²⁾	27	26.1 ⁽⁸⁾	9.22 ⁽¹²⁾
Nitrogen Oxides (NO _x) (as NO ₂)	mg/Rm ³ @ 11% O ₂	400 ⁽²⁾	350	207	270	N. Def.	198	197.5 ⁽⁹⁾	183.22 ⁽¹²⁾
Carbon Monoxide (CO)	mg/Rm ³ @ 11% O ₂	57 (114 for RDF Systems) ⁽¹⁾	55 (14)	N. Def.	N. Def.	N. Def.	40	41 to 200 ⁽¹⁰⁾	45.82 ⁽¹²⁾
Cadmium (Cd)	µg/Rm ³ @ 11% O ₂	100 ⁽²⁾	100 ⁽¹⁵⁾	14	14	N. Def.	7	7.0	N. Def.
Lead (Pb)	µg/Rm ³ @ 11% O ₂	50 ⁽²⁾	50 ⁽¹⁵⁾	142	140	N. Def.	60	98.0	N. Def.
Mercury (Hg)	µg/Rm ³ @ 11% O ₂	20 ⁽³⁾	200 ⁽¹⁵⁾	20	35 ⁽¹⁹⁾	N. Def.	20	35.0	45.83 ⁽¹³⁾
Cd + Tl	µg/Rm ³ @ 11% O ₂	N. Def.	N. Def..	N. Def.	N. Def.	N. Def.	N. Def.	N. Def.	45.83 ⁽¹³⁾
Sum (Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V)	µg/Rm ³ @ 11% O ₂	N. Def.	N. Def.	N. Def.	N. Def.	N. Def.	N. Def.	N. Def.	458.13 ⁽¹³⁾
PCDD/F TEQ (Dioxins and Furans)	ng/Rm ³ @ 11% O ₂	0.08 ⁽⁴⁾	0.5 ⁽¹⁶⁾	0.08	25 ⁽²⁰⁾	N. Def.	0.08	9.1 ⁽¹¹⁾	0.092
Organic Matter (as Methane)	mg/Rm ³	N. Def.	N. Def.	65.6	N. Def.	N. Def.	33	N. Def.	N. Def.
Opacity	%	5	5		10	5	5 (2 hour avg) and 10 (6 minute avg)	10	

NOTES:

- N. Def. = Not Defined
- Concentration Units: Mass per reference cubic metres corrected to 11% oxygen and 0% moisture. Reference conditions: 25°C, 101.3 kPA, except British Columbia which is based on 20°C
- (1) CCME Operating and Emissions Guidelines for MSW Incinerators Report CCME-TS/WM-TRE003, June 1989. Table 4.2: Stack Discharge Limits (at 11% O₂)
- (2) CCME Operating and Emissions Guidelines for MSW Incinerators Report CCME-TS/WM-TRE003, June 1989. Table 4.3: Anticipated Emissions from MSW Incinerators
- (3) CCME Canada-Wide Standards for Mercury Emissions (2000)
- (4) CCME Canada-Wide Standards for Dioxins and Furans (2001) - 2007 review determine no need to update
- (5) Large' = Large MWC units with an individual MWC capacity greater than 250 tons/d
- (6) Units have been converted to Ontario MOE A-7 concentration units to allow direct comparison
- (7) Or 80% reduction by weight or volume of potential SO₂ emissions, whichever is less stringent
- (8) Or 95% reduction of potential HCl emissions by weight, whichever is less stringent
- (9) 180 ppmdv @ 7% O₂ for 1st year of operation, 150 ppmdv @ 7% O₂ after 1st year of operation
- (10) CO limit varies per technology: 40 mg/Rm³ @11% O₂ for Modular Starved-Air & Excess Air Unit; 200 mg/Rm³ @11% O₂ for Spreader Stoker Refuse-derived fuel
- (11) Limit not comparable to Canadian and European limits. Dioxins/furans on total mass basis measured as tetra- through octachlorinated dibenzo-p-dioxins and dibenzofurans. Not TEQ values
- (12) Daily average value
- (13) Average values over the sample period of a minimum of 30-minutes and a maximum of 8 h
- (14) For RDF systems the limit shall be 110 mg/m³
- (15) The concentration is total metal emitted as solid and vapour
- (16) Expressed as Toxicity Equivalents. The value shall be estimated from isomer specific test data and toxicity equivalency factors by following a procedure approved by the ministry
- (17) Or 25% of the potential SO₂ emission concentration (75% reduction by weight or volume), whichever is less stringent.
- (18) Or 5% of the potential HCl emission concentration (95% reduction by weight or volume), whichever is less stringent.
- (19) Or 15% of the potential mercury emission concentration (85% reduction by weight), whichever is less stringent.
- (20) Total mass. Applies to municipal waste combustor units that employ electrostatic precipitator-based emission control system. If electrostatic precipitator-based emission controls are not employed, 15 ng per dry m³ (total mass) @ 7% O₂.

Table 9-20: Permitted Emission Limit Values from Various Existing and Proposed Facilities Worldwide

Component	Unit	Metro Vancouver WTE Facility (Canada)	Durham/York Facility Proposed ^[1] (Canada)	SEMASS Boiler No. 3 (US) ^[3]	Spittelau (Austria) ^[10]		Zisterdorf (Austria) ^[10]		SITA Isle of Man Incinerator ^[2]			Linz (Austria) ^[7]	I/S Reno-Nord WTE (Denmark) Facility ^[5]			SELCHP (England) ^[6]	TREA Breisgau (Germany) ^[8]			Coventry WTE Facility (UK) (2009 Permit) ^[9]			Lungsjoverket (Sweden) ^[11]	
					Half Hour Average	Periodic	Half Hour Average	Periodic	Half Hour Average	Daily Average	Periodic	Half Hour Average	Daily Average	Periodic	Daily Average	Daily Average	Periodic	Half Hour Average	Daily Average	Periodic	Half Hour Average	8 Hour Average		
Total Particulate Matter	mg/m ³	20	9.2	19.6	14.0		7.5		28.0	9.3		4.7	9.3		9.3	4.7		28.0	9.3	28.0	9.3			
CO	mg/m ³	55	45.8	124.9	93.2		46.6		93.2	46.6					46.6			93.2	46.6	93.2				
SO ₂	mg/m ³	200	35.6	55.0	37.3		18.6		186.3	46.6		37.3	18.6		46.6	9.3		186.3	46.6	186.3	46.6			
NO _x	mg/m ³	350	123.1	245.0	93.2		65.2		372.7	186.3		55.9			186.3	65.2		372.7	167.7	372.7	139.8			
HCl	mg/m ³	55	9.2	27.0	18.6		6.5		55.9	9.3		6.5	4.7		9.3	4.7		55.9	9.3	55.9	9.3			
HF	mg/m ³	3			0.7		0.3				1.9	0.28	0.9							1.9				
TOC	mg/m ³					18.6		7.5	18.6	9.3		7.5			9.3	4.7		18.6	9.3	18.6	9.3			
Methane	mg/m ³	40	49.8																					
As	mg/m ³	0.004																						
Cr	mg/m ³	0.01																						
Hg	mg/m ³	0.2	0.015	0.020		0.093		0.047			0.047			0.047		0.009				0.047				
Cd	mg/m ³	0.1	0.007	0.029		0.093		0.009																
Cd,Tl	mg/m ³		0.047								0.047			0.047			0.009			0.047				
Pb	mg/m ³	0.05	0.051	0.313																				
Sum of As, Ni, Co, Pb, Cr, Cu, V, Mn, Sb	mg/m ³		0.47								0.47			0.47			0.093			0.47				
Dioxins/Furans I-TEQ	ng/m ³	0.5	0.061	22.9 ^[4]				0.093			0.093			0.093			0.047			0.093		0.093		

NOTES:
N. Def. = Not Defined
Concentration Units: Mass per reference cubic metres corrected to 11% oxygen and 0% moisture. Reference conditions: 20°C, 101.3 kPa,
(1) Submitted to the Regions of Durham York from Covanta Energy Corporation.
(2) SITA Isle of Man Annual Public Report 2008.
(3) SEMASS Resource Recovery Facility Technology Description and Performance History
(4) ng/Ncm (tetra-octa) - not comparable to TEQ values (same conditions except 0 degrees C)
(5) Jeff Harnly. Europe's Continued Progress with Waste to Energy. Xcel Energy. (periodic measurements over a period of a minimum of 30 minutes and a maximum of 8 hours except dioxins/furans which is over a minimum of 6 hours and a maximum of 8 hours)
(6) Obtained from <http://www.selchp.com/emissions.asp>.
(7) Federal Environment Agency. 2009. Presentation entitled "Waste Management in Austria, How to Avoid Wasting Waste".
(8) Jeff Harnly. Europe's Continued Progree with Waste to Energy. Xcel Energy. (periodic measurements over a period of a minimum of 30 minutes and a maximum of 8 hours except dioxins/furans which is over a minimum of 6 hours and a maximum of 8 hours)
(9) Environment Agency. 2009. The CSWDC Waste to Energy Plant Permit Number NP3739PD.
(10) Federal Environment Agency - Austria. 2002. State of the Art for Waste Incineration Plants.
(11) LJUNGSJÖVERKET - PHASE 2 Waste Incineration Plant. Volund Systems Waste and Energy Technologies.

Table 9-21: Overview of Key Jurisdictions Emission Criteria and Limits with Respect to Averaging Periods

Contaminant	Concentration Units	British Columbia Emission Criteria for Municipal Solid Waste Incineration (1991)			US EPA Emissions Criteria for Large Municipal Waste Combustors (May 10, 2006) (8)			European Union Waste Incineration Directive (2000)			Ontario MOE A-7 (October 2010)	
		Facilities Processing >400 kg/h	Average Period	Monitoring Method	New Large Facilities	Averaging Period	Monitoring Method	Daily Average (CEMS) (14)	Half Hourly (100%) (CEMS) (9)	Half Hourly (97%) (CEMS) (10)	In-Stack Emission Limit	Verification of Compliance (15) Period
Total Particulate Matter (TPM)	mg/Rm ³ @ 11% O ₂	20	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager	14.2			9.3	28	9	13.0	Results from compliance source testing or calculated as the rolling arithmetic average of four (4) hours of data before dilution with any other gaseous stream, measured by a continuous emission monitoring system that provides data at least once every fifteen minutes.
Carbon Monoxide (CO)	mg/Rm ³ @ 11% O ₂	55	4-hour rolling average	Continuous Monitoring	42-203 (6)			46.6	93.2 or 139.8 (1)		37.3	Calculated as the rolling arithmetic average of four (4) hours of data at the outlet of the piece of equipment where combustion of the gas stream resulting from thermal treatment of waste is completed but before dilution with any other gaseous stream, measured by a continuous emission monitoring system that provides data at least once every fifteen minutes.
Sulphur Dioxide (SO ₂)	mg/Rm ³ @ 11% O ₂	250	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager	56 (3)			46.6	186	47	52.2	Results from compliance source testing or calculated as the rolling arithmetic average of 24 hours of data measured by a continuous emission monitoring system that provides data at least once every 15 minutes.
Nitrogen Oxides (NO _x as NO ₂)	mg/Rm ³ @ 11% O ₂	350	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager	201 (5)			186.3	373	186	184.5	Results from compliance source testing or calculated as the rolling arithmetic average of 24 hours of data measured by a continuous emission monitoring system that provides data at least once every 15 minutes.
Hydrogen Chloride (HCl)	mg/Rm ³ @ 11% O ₂	70	8-hour rolling average	Continuous Monitoring	26.5 (4)			9.3	56	9	25.2 (2)	Results from compliance source testing or calculated as the rolling arithmetic average of 24 hours of data measured by a continuous emission monitoring system that provides data at least once every 15 minutes.
Hydrogen Fluoride (HF)	mg/Rm ³ @ 11% O ₂	3	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager	N.D.			0.93 (12)	3.7 (12)	1.9 (12)	N.D.	
Total Hydrocarbons (as CH ₄)	mg/Rm ³ @ 11% O ₂	40	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager	N.D.			N.D.	N.D.	N.D.	N.D.	
Organic Matter (as CH ₄)	mg/Rm ³ @ 11% O ₂	-	N.D.	N.D.	N.D.			N.D.	N.D.	N.D.	30.7	Results from compliance source testing or calculated as the rolling arithmetic average of 10 minutes of data at the outlet of the piece of equipment where combustion of the gas stream resulting from thermal treatment of waste is completed but before dilution with any other gaseous stream takes place, measured by a continuous emission monitoring system that provides data at least once every minute.
VOCs (as Total Organic Carbon)	mg/Rm ³ @ 11% O ₂	-	N.D.	N.D.	N.D.			9.3	19	9.3	N.D.	
Arsenic (As)	µg/Rm ³ @ 11% O ₂	4	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager	N.D.			N.D.			N.D.	
Cadmium (Cd)	µg/Rm ³ @ 11% O ₂	100	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager	7.1			N.D.			6.5	Calculated as the arithmetic average of three stack tests conducted in accordance with standard methods
Chromium (Cr)	µg/Rm ³ @ 11% O ₂	10	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager	N.D.			N.D.			N.D.	
Lead (Pb)	µg/Rm ³ @ 11% O ₂	50	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager	99.7			N.D.			55.9	Calculated as the arithmetic average of three stack tests conducted in accordance with standard methods

Contaminant	Concentration Units	British Columbia Emission Criteria for Municipal Solid Waste Incineration (1991)			US EPA Emissions Criteria for Large Municipal Waste Combustors (May 10, 2006) (8)			European Union Waste Incineration Directive (2000)	Ontario MOE A-7 (October 2010)	
Cadmium (Cd) and Thallium (Tl)	µg/Rm ³ @ 11% O ₂	-	N.D.	N.D.	N.D.			47 (non continuous - average over period of min. 30 minutes and max. 8 hours) (11) (13)	N.D.	
Mercury (Hg)	µg/Rm ³ @ 11% O ₂	200	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager	35.6			47 (non continuous - average over period of min. 30 minutes and max. 8 hours) (11) (13)	18.6	Calculated as the arithmetic average of 24 hours of data measured by as CEMS that provides data every 15 minutes
Sum of Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V	µg/Rm ³ @ 11% O ₂	-	N.D.	N.D.	N.D.			470 (non continuous - average over period of min. 30 minutes and max. 8 hours) (11) (13)	N.D.	
Chlorophenols	µg/Rm ³ @ 11% O ₂	1	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager	N.D.			N.D.	N.D.	
Chlorobenzenes	µg/Rm ³ @ 11% O ₂	1	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager	N.D.			N.D.	N.D.	
Polycyclicaromatic Hydrocarbons	µg/Rm ³ @ 11% O ₂	5	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager	N.D.			N.D.	N.D.	
Polychlorinated Biphenyls	µg/Rm ³ @ 11% O ₂	1	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager	N.D.			N.D.	N.D.	
Total PCDD/F TEQ (Dioxins and Furans)	ng/Rm ³ @ 11% O ₂	0.5	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager	9.3 (7)			0.093 (non continuous - average over min. 6 hours and max. 8 hours) (11) (13)	0.075	Results from compliance source testing; results expressed as I-TEQ.
Opacity	%	5	1-hour average from data taken every 10 seconds	Continuous Monitoring	10			N.D.	10% and 5%	(10%) calculated as the rolling arithmetic average of six (6) minutes of data measured by a continuous emission monitoring system that provides data at least once every minute or (5%) calculated as the rolling arithmetic average of two (2) hours of data measured by a continuous emission monitoring system that provides data at least once every fifteen minutes

NOTES:
 Concentration units: Mass per reference cubic metres corrected to 11% oxygen. Reference conditions: 20 deg. C, 101.3 kPa, dry gas
 N.D. = Not Defined
 (1)139.8 if 95% of all measurements determined as 10-minute average values or 93.2 determined as half-hourly values taken in any 24 hour period (exemptions may be authorized by the competent authority for incineration plants using fluidized bed technology, provided that the permit foresees an emission limit value for carbon monoxide (CO) of not more than 93.2 mg/m³ as an hourly average value.)
 (2) Or an HCl removal efficiency of not less than 95%
 (3) or 80% reduction by weight or volume of potential SO₂ emissions, whichever is less stringent
 (4) or 95% reduction of potential HCl emissions by weight, whichever is less stringent
 (5) 180 ppm_{dv} @ 7% O₂ for the 1st year of operation, 150 ppm_{dv} @ 7% O₂ after 1st year of operation
 (6) CO limit varies per technology: 40 mg/Rm³ @ 11% O₂ for Modular Starved-Air and Excess Air Unit; 200 mg/Rm³ @ 11% O₂ for Spreader Stoker Refuse-derived fuel.
 (7) Limit not comparable to Canadian or European limits. Dioxins/furans on a total mass basis measured as tetra- through octachlorinated dibenzo-p-dioxins and dibenzofurans. Not TEQ values.
 (8) 'Large' = Large MWC units with an individual MWC capacity greater than 250 tons/day
 (9) None of the half-hourly values exceeds any of the emission limit values set out.
 (10) 97% of the half-hourly average values over a year do not exceed any of the emission limit values set out.
 (11) At least two measurements per year; one measurement at least every three months shall however be carried out for the first 12 months of operation.
 (12) The continuous measurements of HF may be omitted if treatment stages for HCl are used which ensure that the emission limit value for HCl is not being exceeded. In this case the emissions of HF shall be subject to periodic measurements as laid down in (11).
 (13) The reduction in the frequency of the periodic measurements from twice a year to once every year may be authorized by the competent authority provided that the emissions are below 50% of the emission limit values.
 (14) No more than five half-hourly average values in any day shall be discarded due to malfunction or maintenance of the CEMS. No more than ten daily average values per year shall be discarded due to malfunction or maintenance of the CEMS.
 (15) Compliance source testing as set out in the facility's Certificate of Approval.

9.3 Application of Emission Limits in BC

9.3.1 Setting Objectives and Standards for Existing and New Facilities

As discussed in the sections above, the regulatory review process in BC includes a combination of processes that may be triggered according to size of the WTE facility. In BC, these limits are to be determined in accordance with the guidance provided by the province's interim Best Achievable Technology (BAT) policy. In brief summary, the BAT policy requires the setting of limits based on what is technically and economically feasible and in general accordance with accepted practice at other similar facilities. Governing the emissions to atmosphere, however, is the EMA and associated codes of practice, regulations and guidelines (used as the basis for setting permit limits or for WTE facilities limits within SWMPs). The regulatory framework in BC currently utilizes the 1991 British Columbia Criteria for Municipal Solid Waste Incinerators as well as the BC Air Quality Objectives (last amended in April 2009). Emission guidelines and air quality objectives are non-statutory limits that are used by the regulatory agencies to guide decisions with respect to allowable concentrations of air pollutants in the discharge and ambient air.

The current system has been in place for many years and in general is functioning satisfactorily. The MSW Criteria specify the general conditions for which these facilities must be operated, but it is the permit or the SWMP that determines the average and maximum permissible point source concentrations of contaminants that may be discharged. These point source limits are based on the various guidelines directly for point source emissions, and indirectly for impacts to ambient air quality.

9.3.2 Operational Variability

All industrial processes have some variability. Specifically with WTE combustion technology, variability is inherent in the process and in the incoming MSW material stream, and the control of the facility operating conditions is the mandate of the operators so that the emission quality (and other operational parameters) is met. Operators try to minimize the variability of the process to provide a higher quality operation, but some variability in the operation and emission quality is certain.

In the combustion sector, particularly for WTE, there is a difference between the absolute minimum concentrations of emission constituents that will be released from the facility during periods of normal operating conditions and those greater concentrations that can be 'reasonably' expected to be produced during brief periods of operational and/or material stream flux. Well designed, maintained and operated facilities are able to achieve the lower emission values a large proportion of the time, generally over 95% of the time, potentially approaching 97% or more. During periods of upset conditions, however, such as during some upset in combustion or in the treatment works, the concentration of emissions may increase over a short period of time until the issue is resolved and normal conditions return. The frequency and magnitude of this variance is facility-specific and is mitigated to the extent possible by the use of CEMs to constantly monitor operating conditions and in the design of the facility and air pollution control systems.

As a result, some jurisdictions have addressed the need to set regulatory emissions limits that reflect not only BAT but the expectations for performance under both normal and upset conditions, and monitoring methods, by applying averaging periods for the emissions of various parameters and expectations on how emissions would be monitored in order to demonstrate compliance.

9.3.3 Setting Emission Limits

The regulator desires to regulate the discharge such that:

- a) The emission to atmosphere in all cases does not cause a risk to human health and the environment.
- b) The emission limit imposes an obligation on the operator to achieve the lowest practical emission concentrations for the maximum period of time.
- c) The emission limit is set such that it is achievable by the operator, is reasonable in terms of cost to meet the limit and meets the protective requirements and is consistent with the available monitoring equipment and techniques for a specific parameter.

Best Available Control Technology (BACT) refers to the use of equipment, operational practice and treatment systems to produce an emission that represents the best of technology for the sector. BACT is always changing because of advancements in technology. There is sufficient comparable technology in the WTE sector, as evidenced in our report, to establish BACT-based limits for the WTE sector in BC. In depth studies of BACT for WTE in other jurisdictions undertaken in part to support the establishment of new regulatory limits, indicate that the quality of air emissions from this sector have continually improved over the past 20 years (i.e., lower concentrations are being realized).^[243]

In order to meet the three points above, consideration of a combination of factors, including: emission quality (concentration and/or mass loading to the environment); variability of the emission (frequency and magnitude of the variance); and, monitoring/testing technique limitations, is necessary in the setting of the regulatory limits. Setting a limit too high does not incent the operator to strive to improve emission quality to meet the “best achievable” quality. Setting a limit too low may not be consistently achievable by the operator on a time scale consistent with the operation of the facility. This is the essence of the problem posed with setting limits.

9.3.4 Proposed Approach

The proposed change in regulatory approach suggested as an outcome of the review of WTE technologies, emissions quality from operating WTE and regulatory approaches in other jurisdictions, is based on the consideration of emissions parameters considered suitable as an indicator of facility performance, averaging periods and establishment of monitoring expectations as part of the specified emission limits. BACT would form the basis for the emission limits, and the averaging periods for a specific test would relate to the application of the BACT limit.

²⁴³ Ministry of Housing, Spatial Planning and the Environment. 2002. Dutch Notes on BAT for the Incineration of Waste

In simple terms, we suggest that for any specific parameter, that a maximum concentration “not to be exceeded” be established, representing an emission quality that is consistent with BACT which is also protective of human health and the environment. Concentrations in excess of this amount would be considered non-compliant and would require the facility to undertake immediate mitigation to improve the quality of emission. This approach is consistent with the current method used by BC to regulate air emissions. The difference between the current and proposed approaches is the identification of appropriate values that are specific to averaging periods that reflect both reasonable expectations for performance and the methods that would normally be used to demonstrate compliance.

Two averaging periods would be applicable for most emission parameters, and would be consistent with the approach applied in many jurisdictions where there continues to be significant application of WTE as a means of managing waste:

- a) Application of ½ hour averaging periods for specific parameters that reflect the expectations of performance for a facility under all operating conditions (normal or upset). Such limits would apply only to those parameters that can be continuously monitored, and that should be continuously monitored in order to ensure that expectations for operating performance are achieved.
- b) Application of ‘daily’ averages for a broader range of parameters, that reflect the expectations of performance for a facility under normal operating conditions, as determined through CEM or the averaging of the results from stack (source) testing depending on the parameter.

With respect to policy and perception, we view the use of dual values as the most effective manner to regulate emissions to the most reasonably stringent degree. The maximum value (half-hourly) will be protective in all cases. The statistical or average value (daily) will be even lower in numerical value than the maximum value, illustrating and recognizing that the expected emission quality can be much better than the maximum value on an on-going basis. This approach encourages the industry to install BACT and encourages resolution of operational issues in a timely fashion in order to meet the lowest possible value on an ongoing basis.

The use of average emission concentrations over both short and longer averaging periods is consistent with the regulatory limits in other jurisdictions. As shown in Tables 9-19 and Table 9-20, European Union limits rely on continuous monitors for many parameters and establish the compliance limit on a one-half hour average. As discussed earlier, stack tests generally approximate ‘daily’ averages. In almost no cases are instantaneous values used for compliance.

It is possible to define emission limits in relation to BAT, relative to other jurisdictions and at concentrations protective of human health and the environment in all cases, as set out in Table 9-21, below. Maximum emission concentration limits suggested for application over ½ hourly or daily averaging periods are presented. The suggested averaging periods and the appropriate emission limits considering averaging are consistent with the approach applied in other jurisdictions, and in regards to the majority of parameters are lower than the current emissions limits in effect in BC as these lower limits can be reasonably achieved through BAT.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 9: Emission Limits and Their Application

The actual value that would be applied to a given WTE facility, through the application to amend a current permit (e.g., for an upgrade to a current plant) or for a newly proposed facility, would be both parameter and facility based, and should be linked to the ability to sample and monitor the emission and specific facility design. On the basis of current practice in the WTE sector, values for guidance are also provided.

In Table 9-22, where non-continuous measurements are indicated, the averaging period does not apply. Sampling periods are generally in the order of four to eight hours for such measurements and the ELV is reflective of the averaging of the replicate tests over the monitoring period.

It should be recognized that there are distinct differences in regulatory approaches used in jurisdictions where WTE is a common practice. The proposed measures indicated in Table 9-22 are intended to be generally consistent with the approach that has been applied in BC and reflective of the BACT approaches adopted in other jurisdictions. That being said, some discussion is required to reflect some of the key differences in monitoring approaches and the rationale for the choices recommended for BC.

Organic Matter

During the incineration of organic waste, a large number of chemical reactions take place, some of which may be incomplete, based on the efficiency of the combustion process. Emissions of organic parameters depend on the grate and furnace design, and the optimal provision of incineration air, control of temperature, residence time and the homogeneity of the waste stream. This leads to an extremely complex set of organic compounds that may be emitted in very trace amounts. A complete account of every organic substance is usually not available, however, incineration generally can provide for high destruction efficiencies for organic substances. Various jurisdictions have chosen alternative approaches to monitoring the destruction efficiency and quality of the combustion process. Nearly all jurisdictions set limits on CO emissions, as this is a leading indicator of incomplete combustion, and as a rule CO is usually monitored continuously. However, the point of the flue gas management process at which CO concentrations is monitored does vary; it is generally monitored in the 'combustion gases' within the stack in the EU, and in Ontario and the USA it is monitored at the outlet of the equipment where combustion of the gas stream is completed.

For the broad range of organic compounds that can be emitted, there is significant variation in approaches, however in most cases in addition to CO, some form of organic compounds are required to be monitored and reported. In the EU, total organic carbon (TOC) is monitored and reported as the primary determinant of the emissions of volatile organic carbon (VOCs) and non-methane volatile organic carbon (NMVOC) that make up the large part of the compounds that can be measured continuously as a 'group'. Often the regulatory documents for EU jurisdictions make various references to monitoring TOC, VOCs, NMVOC, CxHy and organic carbon, but they are all essentially referring to one group of organic compounds measured and reported as TOC. In many cases, in addition to TOC, emissions of individual organic parameters or groups such as PCBs and/or PAHs may be reported, but generally there is no specified ELV for these parameters.

BC has been the only jurisdiction where monitoring and reporting of total Hydrocarbons (as CH₄) has been required, although Ontario has used (and continues to use) a similar approach requiring the monitoring and reporting of organic matter (as CH₄), with the point of monitoring being at the outlet of the equipment where combustion of the gas stream takes place. The US is the only jurisdiction where specific monitoring and reporting of the group of organic compounds that can potentially be emitted, is generally not required either by the EPA or under State standards.

Since 1993, there have been shifts in the composition of the MSW stream. The potential for contamination of MSW with materials containing chlorophenols, chlorobenzenes and PCB's has been significantly reduced through regulation so that the potential presence of these parameters in non-hazardous MSW is extremely low. BC is the only jurisdiction where ELVs have been established and applied to chlorophenols, chlorobenzenes, polycyclic aromatic hydrocarbons and polychlorinated biphenyls, although as noted above, many facilities may voluntarily monitor and report on some or all of these parameters.

Generally, given that CEMs for TOC and CO is considered state of the art, and that both parameters are suitable for the application of both ½ hourly and daily limits, a move to the use of this approach (similar to the EU) is recommended for BC.

Trace Heavy Metals

The regulatory approach for heavy metals also varies significantly between jurisdictions. Generally, jurisdictions in North America, set ELVs for individual metals of specific concern, each generally reflective of a 'class' of metals which can be present in different waste sources and that have differences in their potential speciation and behavior in a WTE facility, requiring different management techniques for effective treatment in the flue gas. All jurisdictions use generally the same approach to regulate Mercury (Hg), setting stack ELVs specific to this heavy metal. It is reasonable to continue to do so in BC, setting the limit at the lowest ELV representative of BACT and achievable by modern plants.

All jurisdictions regulate emissions of Cadmium (Cd) and its compounds, although in the EU cadmium is grouped with Thallium (Tl) and an ELV has been established for this combined group of compounds. Cadmium can be present in electronic devices present in municipal waste. Thallium is generally not present in municipal waste it is generally only present in hazardous waste materials. For municipal waste WTE facilities, it generally does not appear reasonable to set an ELV for the group of Cd, Tl and their compounds, but rather to continue to regulate Cd, setting the limit at the lowest ELV representative of BACT and achievable by modern plants.

All jurisdictions regulate emissions of Lead (Pb) and its compounds, although in the EU, Lead is grouped with a number of similar (less-volatile) heavy metals (Antimony, Arsenic, Chromium, Cobalt, Copper, Manganese, Nickel and Vanadium). This group includes carcinogenic metals and metal compounds as well as metals with toxicity potential. Lead and this group of metals are generally bound in dust due to the vapour pressures of their compounds, as contained in the flue gas (mainly oxides and chlorides). BC was the only jurisdiction noted where individual ELVs were established for Arsenic and Chromium. To summarize, there appears to be a range of approaches that could be

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 9: Emission Limits and Their Application

considered in BC, which in various jurisdictions is considered representative of BACT for Lead and similar heavy metals, including:

- Set an ELV and regulate only Lead emissions, as a leading indicator of the potential emissions of the group of similar heavy metals that have potential carcinogenic and/or toxic potential (similar to the Ontario and US approach).
- Set an ELV that is applicable to the group of similar heavy metals (similar to the EU approach), recognizing that this approach would require monitoring of a number of metal parameters that are currently not required to be monitored in BC, and also recognizing that the concentration of any individual heavy metal in the group could reach up to the ELV and theoretically could reach a higher value than current permitted in the Province.
- Set an ELV that is applicable to the group of current similar heavy metals (Lead, Arsenic, Chromium) that is currently required in the Province, setting the value at the sum total of the current permitted limits for these heavy metals (being 64 ug/Rm^3). This approach represents a 'hybrid' of the EU and current B.C. approaches to regulate these metals.
- Continue to set individual ELVs for each of the specific heavy metals (Lead, Arsenic, Chromium) as indicated in the 1991 Guidelines for BC.

The recommended approach that appears to best serve the Province would be a grouping of the three heavy metals (lead, arsenic and chromium), setting the ELV as the sum total of the ELVs of 64 ug/Rm^3 . Establishing an ELV based on the grouping of these three metals allows for heterogeneity in the fuel while maintaining stringent levels protective of human health and the environment.

Particulate and Opacity

The current approach used in North American jurisdictions to monitor and limit emissions of particulate and the opacity of the flue gas stream which is a more indirect determination of particulate emissions, is to apply an ELV at the stack for total particulate matter as determined through periodic stack testing, and to require the continuous monitoring of opacity in the flue gas. Opacity is not a good determinant of compliance with particulate limits; however it is a leading indicator of potential performance issues with the APC system, particularly performance of the bag-house or other devices used to manage particulate. While in North America, particulate emissions are monitored periodically, there are no requirements for CEMS; rather the use of continuous monitoring devices is optional. Generally, in North America CEMS for particulate are considered to be improved but still evolving to address performance issues experienced with older approaches. In the EU, opacity is not regulated through an ELV, rather emissions of total particulate are regulated based on ELVs with $\frac{1}{2}$ hourly and daily averages based on data gathered through continuous emissions monitoring. Use of CEMS for particulate is regarded as part of the application of BACT for WTE facilities.

It is recommended for BC to adopt a hybrid approach. CEMS for particulate would be required for new facilities. Where continuous monitoring systems for particulate are used, opacity monitoring may not be necessary as a compliance parameter unless the continuous monitoring system is not functioning. During this scenario, opacity monitoring can be used as a temporary surrogate until the continuous monitoring system for particulate is reinstated.

Table 9-22: Proposed Revisions to Emission Criteria for Municipal Solid Waste Incineration in British Columbia

Contaminant	Concentration Units	RECOMMENDED EMISSION LIMITS					CURRENT EMISSION LIMITS (1991)		
		C: Continuous P: Periodic ⁽¹⁾	Daily Average	Average Period and Monitoring Method	Half Hourly Average	Average Period and Monitoring Method	Facilities processing >400 kg/h	Average Period	Monitoring Method
Total Particulate Matter (TPM)	mg/Rm ³ @ 11% O ₂	C (P for existing facilities)	9	Existing facilities without CEMS may use the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods. This limit also applies to facilities with CEMS where periodic stack testing is conducted to validate the CEMS or in the event the CEMS is not functional.	9 ⁽²⁾ 28	1/2 hour average as determined by a continuous emissions monitoring system, achieved 97% of the operating period on a 12 month rolling average. 1/2 hour average as determined by a continuous emissions monitoring system, achieved 100% of the operating period on a 12 month rolling average.	20	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager
Carbon Monoxide (CO)	mg/Rm ³ @ 11% O ₂	C	50	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	100	1/2 hour average as determined by a continuous emissions monitoring system	55	4-hour rolling average	Continuous Monitoring
Sulphur Dioxide (SO ₂)	mg/Rm ³ @ 11% O ₂	C	50	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	190	1/2 hour average as determined by a continuous emissions monitoring system	250	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager
Nitrogen Oxides (NO _x as NO ₂)	mg/Rm ³ @ 11% O ₂	C	190	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	350	1/2 hour average as determined by a continuous emissions monitoring system	350	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager
Hydrogen Chloride (HCl)	mg/Rm ³ @ 11% O ₂	C	10	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	60	1/2 hour average as determined by a continuous emissions monitoring system	70	8-hour rolling average	Continuous Monitoring
Hydrogen Fluoride (HF)	mg/Rm ³ @ 11% O ₂	P/C	1	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	4	1/2 hour average as determined by a continuous emissions monitoring system ⁽³⁾ .	3	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager
Total Hydrocarbons (expressed as equivalent CH ₄) ⁽⁴⁾	mg/Rm ³ @ 11% O ₂	N.D.	N.D.		N.D.		40	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager
Total Organic Carbon	mg/Rm ³ @ 11% O ₂	C	10	Calculated as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	20	1/2 hour average as determined by a continuous emissions monitoring system	N.D.		
Arsenic (As)	µg/Rm ³ @ 11% O ₂	P	See Pb, As and Cr grouping	Calculated as the sum of Pb, As and Cr, as determined by arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.		4	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager
Cadmium (Cd)	µg/Rm ³ @ 11% O ₂	P	7	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.		100	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager

Contaminant	Concentration Units	RECOMMENDED EMISSION LIMITS					CURRENT EMISSION LIMITS (1991)		
		C: Continuous P: Periodic ⁽¹⁾	Daily Average	Average Period and Monitoring Method	Half Hourly Average	Average Period and Monitoring Method	Facilities processing >400 kg/h	Average Period	Monitoring Method
Chromium (Cr)	µg/Rm ³ @ 11% O ₂	P	See Pb, As and Cr grouping	Calculated as the sum of Pb, As and Cr, as determined by arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.		10	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager
Lead (Pb)	µg/Rm ³ @ 11% O ₂	P	See Pb, As and Cr grouping	Calculated as the sum of Pb, As and Cr, as determined by arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.		50	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager
Sum of Lead (Pb), Arsenic (As), Chromium (Cr)	µg/Rm ³ @ 11% O ₂	P	64	Calculated as the sum of Pb, As and Cr, as determined by arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.		50	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager
Mercury (Hg)	µg/Rm ³ @ 11% O ₂	P or C ⁽⁴⁾	20	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	N.D.		200	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager
Chlorophenols ⁽⁵⁾	µg/Rm ³ @ 11% O ₂	P	1	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.		1	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager
Chlorobenzenes ⁽⁵⁾	µg/Rm ³ @ 11% O ₂	P	1	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.		1	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager
Polycyclicaromatic Hydrocarbons ⁽⁵⁾	µg/Rm ³ @ 11% O ₂	P	5	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.		5	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager
Polychlorinated Biphenyls ⁽⁵⁾	µg/Rm ³ @ 11% O ₂	P	1	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.		1	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager
Total Dioxins and Furans (as PCDD/F TEQ)	ng/Rm ³ @ 11% O ₂	P	0.08	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.		0.5	To be monitored over the approved sampling and monitoring period	Methods to be approved by Regional Manager
Opacity ⁽⁶⁾	%	C (P optional for existing facilities)	N.D.		5	1/2-hour average from data taken every 10 seconds, measured by a CEMS	5	1-hour average from data taken every 10 seconds	Continuous Monitoring

NOTES:

Concentration units: Mass per reference cubic metres corrected to 11% oxygen. Reference conditions: 20°C, 101.3 kPa, dry gas

N.D. = Not Defined

⁽¹⁾ Where Periodic stack test measurements (P) are indicated, the daily averaging period applies. For Continuous monitoring (C), the 1/2 hour averaging period applies. P/C indicates both technologies are available; ELV will be linked to sampling method.

⁽²⁾ 97% of the half-hour average values over an annual rolling average will not exceed 9 mg/Rm³. 100% of the half-hour average values will not exceed 28 mg/Rm³.

⁽³⁾ This requirement may be omitted at the discretion of the Regional Manager should treatment stages for HCl demonstrate that the ELV for HCl is not exceeded.

⁽⁴⁾ Daily Average ELV for mercury applies regardless of monitoring method.

⁽⁵⁾ Proponents may be able to demonstrate that monitoring both Total Organic Carbon (TOC) and Total Dioxin and Furans could negate the need to monitor Chlorophenols, Chlorobenzenes, Polycyclic Aromatic Hydrocarbons and Polychlorinated Biphenyls.

⁽⁶⁾ Opacity will not be required for compliance purposes for facilities utilizing continuous particulate monitoring systems. Opacity monitoring is recommended for operational monitoring purposes. However, monitoring opacity can be used as a temporary surrogate for total particulate monitoring in the event a particulate monitoring system failure. Under these circumstances, the ELV of 5% opacity over a 1/2 hour averaging period should apply.

Table 9-23 summarizes the rationale for recommended values for the ½ hourly or daily averaging periods as set out in Table 9-22.

Table 9-23: Rationale for Recommended Values for the ½ Hourly or Daily Averaging Periods

Parameter	Rationale for Daily Average	Rationale for ½ Hourly Average
TPM	<p>The 1991 BC Criteria limit is 20 mg/Rm³ on a daily basis with compliance based on manual stack testing.</p> <p>The new proposed limit would be 10 mg/Rm³ on a daily basis using a CEM system. This is similar to the EU standard and is stricter than the EPA and Ontario standards.</p>	<p>The 1991 BC criteria limit is 20 mg/Rm³ with compliance based on manual stack testing, which typically occurs quarterly each year. The proposed limits are consistent with the EU ½ hourly averages which are coupled to CEM monitoring. Thus, compliance is determined every half hour.</p> <p>The limit of 9 mg/Rm³ is based on ½ hour averages throughout the year, to be achieved 97% of the time, as an annual rolling average. During rare occasions when upsets in the process or treatment systems cause the 9 mg/Rm³ limit to be exceeded the upper limit of 28 mg/Rm³ is never to be exceeded. Thus, even when emission control systems require service, the 28 mg/Rm³ limit would remain in effect.</p> <p>Comparing the 1991 and proposed emission limits for particulate is difficult because they are monitored in completely different ways. The use of a CEM ensures that emissions are maintained at low levels on a consistent basis, whereas limits based on manual stack sampling do not have such assurance. That said, it is reasonable to suggest that a course comparison of the 20 mg/m³ limit to the proposed limit of 9 mg/Rm³ is a reasonable benchmark comparison. Thus, the new proposed limit is considerably more stringent than the one set in 1991.</p>
CO	<p>The 1991 BC Criteria limit is 55 mg/Rm³ on a daily basis with compliance based on a CEM system.</p> <p>The new proposed limit would be 50 mg/Rm³ on a daily basis using a CEM system. This is similar to the Ontario, EPA and EU standards.</p>	<p>The 1991 BC Criteria limit is 55mg/Rm³ on a daily basis with compliance based on a CEM system.</p> <p>There would also be a new proposed limit of 100 mg/Rm³ on a ½ hourly basis using a CEM system. This would provide a stricter control on maximum allowable emissions. This is similar to the EU standard.</p>
SO ₂	<p>The 1991 BC Criteria limit is 250 mg/Rm³ on a daily basis with compliance based on a CEM system.</p> <p>The new proposed limit would be 50 mg/Rm³ on a daily basis using a CEM system. This is similar to the Ontario, EPA, and EU standards.</p>	<p>The 1991 BC Criteria limit is 250 mg/Rm³ on a daily basis with compliance based on a CEM system.</p> <p>There would also be a new proposed limit of 190 mg/Rm³ on a ½ hourly basis using a CEM system. This would provide a stricter control on maximum allowable emissions. This is similar to the EU standard.</p>

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 9: Emission Limits and Their Application

Parameter	Rationale for Daily Average	Rationale for ½ Hourly Average
NO _x as NO ₂	<p>The 1991 BC Criteria limit is 350 mg/Rm³ on a daily basis with compliance based on a CEM system.</p> <p>The new proposed limit would be 190 mg/Rm³ on a daily basis using a CEM system. This is stricter than the Ontario and EPA standards and similar to the EU standard.</p>	<p>The 1991 BC Criteria limit is 350 mg/Rm³ on a daily basis with compliance based on a CEM system.</p> <p>There would also be a new proposed limit of 350 mg/Rm³ on a ½ hourly basis using a CEM system. This would provide a stricter control on maximum allowable emissions. This is stricter than the EU standard.</p>
HCl	<p>The 1991 BC Criteria limit is 70 mg/Rm³ on a daily basis with compliance based on manual stack testing.</p> <p>The new proposed limit would be 10 mg/Rm³ on a daily basis using a CEM system. This is stricter than the Ontario and EPA standards and similar to the EU standard.</p>	<p>The 1991 BC Criteria limit is 70 mg/Rm³ on a daily basis with compliance based on manual stack testing.</p> <p>There would also be a new proposed limit of 60 mg/Rm³ on a ½ hourly basis using a CEM system. This would provide a stricter control on maximum allowable emissions. This is similar to the EU standard.</p>
HF	<p>The 1991 BC Criteria limit is 3 mg/Rm³ on a daily basis with compliance based on manual stack testing.</p> <p>The new proposed limit would be 1 mg/Rm³ on a daily basis using a CEM system. This is similar to the EU standard.</p>	<p>The 1991 BC Criteria limit is 3 mg/Rm³ on a daily basis with compliance based on manual stack testing.</p> <p>There would also be a new proposed limit of 4 mg/Rm³ on a ½ hourly basis using a CEM system. This would provide a stricter control on maximum allowable emissions. This is similar to the EU standard.</p>
Organic Matter as CH ₄	<p>NA – the parameters, organic matter, total hydrocarbons, and TOC are all primarily indicators of combustion efficiency although they may be monitored at different points of the process. A stack emission limit is not recommended for Organic Matter as the most appropriate monitoring point is at the outlet of the point of the process where combustion of the gas stream is completed. A stack emission limit is only being recommended for TOC.</p>	<p>NA – no value proposed. While regulation of emissions of organic matter at the outlet of the equipment where combustion of the gas stream takes place is a means of monitoring combustion efficiency, monitoring of TOC as discussed below can be accomplished through the use of CEMs and is consistent with BACT in the EU.</p>
Total Hydrocarbons (as CH ₄)	<p>NA – see organic matter rationale – no value proposed. The 1991 BC Criteria limit is 40 mg/Rm³ on a daily basis with compliance based on manual stack testing.</p> <p>A regulatory limit for hydrocarbons is best addressed through limits on Volatile Organic Compounds (see VOCs below).</p>	<p>NA – no value proposed. A regulatory limit for hydrocarbons is best addressed through limits on Volatile Organic Compounds (see VOCs below).</p>
TOC	<p>Consistent (rounded) with EU daily average.</p>	<p>Consistent (rounded) with EU ½ hourly values achieved 100% of the time.</p>

Parameter	Rationale for Daily Average	Rationale for ½ Hourly Average
As	<p>The 1991 BC Criteria limit is 0.004 mg/Rm³ with compliance based on manual stack testing.</p> <p>The new proposed limit would be on a class basis for As/Cr/Pb which exhibit similar properties, the limit would be set at 0.064 mg/Rm³. This approach is similar to EU standard (EU class basis includes Sb, As, Pb, Cr, Co, Cu, Mn, Ni, and V); no other jurisdictions have set a standard for arsenic.</p>	NA
Cd	<p>The 1991 BC Criteria limit is 0.1 mg/Rm³ with compliance based on manual stack testing.</p> <p>New proposed limit would be 0.014 mg/Rm³ which is the same as the Ontario standard. This limit is stricter than the EPA standard; the EU sets a combined limit for cadmium and thallium.</p>	NA
Cr	<p>The 1991 BC Criteria limit is 0.01 mg/Rm³ with compliance based on manual stack testing.</p> <p>The new proposed limit would be class basis for As/Cr/Pb which exhibit similar properties, the limit would be set at 0.064 mg/Rm³. This approach is similar to EU standard (EU class basis includes Sb, As, Pb, Cr, Co, Cu, Mn, Ni, and V); no other jurisdictions have set a standard for chromium.</p>	NA
Pb	<p>The 1991 BC Criteria limit is 0.05 mg/Rm³ with compliance based on manual stack testing.</p> <p>The new proposed limit would be class basis for As/Cr/Pb which exhibit similar properties, the limit would be set at 0.064 mg/Rm³. This approach is similar to EU standard (EU class basis includes Sb, As, Pb, Cr, Co, Cu, Mn, Ni, and V); Ontario is the only other jurisdiction to set a proposed limit for lead this limit has yet to be included in a final authorization.</p>	NA
Mercury	<p>The 1991 BC Criteria limit is 0.2 mg/Rm³ with compliance based on manual stack testing.</p> <p>New proposed limit would be 0.02 mg/Rm³ is consistent with the CCME Canada Wide Standard and Ontario standard. The proposed limit is stricter than the EPA and EU standards.</p>	NA

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 9: Emission Limits and Their Application

Parameter	Rationale for Daily Average	Rationale for ½ Hourly Average
Chlorophenols	The 1991 BC Criteria limit is 1 ug/Rm ³ with compliance based on manual stack testing. The new proposed limit remains the same, other jurisdictions (e.g., EPA, EU) do not have a set limit for chlorophenols.	NA
Chlorobenzenes	The 1991 BC Criteria limit is 1 ug/Rm ³ with compliance based on manual stack testing. The new proposed limit remains the same, other jurisdictions (e.g., EPA, EU) do not have a set limit for chlorobenzenes.	NA
PAHs	The 1991 BC Criteria limit is 5 ug/Rm ³ with compliance based on manual stack testing. The new proposed limit remains the same, other jurisdictions (e.g., EPA, EU) do not have a set limit for PAH's.	NA
PCBs	The 1991 BC Criteria limit is 1 ug/Rm ³ with compliance based on manual stack testing. The new proposed limit remains the same, other jurisdictions (e.g., EPA, EU) do not have a set limit for PCBs.	NA
Total PCDD/F TEQ	The 1991 BC Criteria limit is 0.5 ng/Rm ³ with compliance based on manual stack testing. New proposed limit would be 0.08 ng/Rm ³ is consistent with the CCME Canada Wide Standard and Ontario standard. The proposed limit is stricter than the EPA and EU standards.	NA
Opacity	NA	The 1991 BC Criteria limit is 5% on a 1 hour average with compliance based on CEM measurements every 10 seconds. The proposed limit is 5%, also based on CEM, on a 1/2 hour basis. This parameter would be a backup to particulate monitoring in the event that the CEM systems were unavailable. The proposed limit is consistent with Ontario and EPA standards.

Comparison to the Permitted Values and Monitoring Approach for the Burnaby WTE Facility

In order to demonstrate the viability of the proposed regulatory approach for WTE emissions in BC, it is reasonable to conduct a comparison to the extent possible to the current permitted limits and actual emissions data for the only operating WTE facility in the Province. Table 8-7 provides an overview of the permitted air emissions limits as applied to the WTE facility in Burnaby and actual emissions reported as of 2007.

Note: as a point of interest, application of the MACT approach as used in the USA, results in the setting of regulatory emissions limits based on the emissions from the top percentage of existing facilities. This approach could not be easily used in BC given that there is currently only one operating plant. However, comparison of the emissions from the Burnaby plant to the proposed emissions limits is reasonable.

Note, that the proposed ½ hour and 24 hour emissions limits are not directly comparable to the current permits and performance of the Burnaby WTE facility. The permitted discharge limits for the Burnaby plant are generally applied as a 'not to exceed' limit which is closer the proposed ½ hour limits for emissions (to be achieved 100% of the time). There are no comparable equivalents using the data provided in Table 8-7 to the proposed 24 hour limits, additional information regarding current emissions as measured by CEMS is required for comparison.

Comparing the permitted and actual values with the suggested ½ hourly averages for application in BC indicates that:

- The proposed ½ hourly limits are generally comparable to the discharge limits set out in the current permit, and are generally comparable to the ½ hour averages for the key parameters that are normally monitored by CEMS (acid gases, NO_x and CO). Actual 2007 emissions information indicates that the proposed ½ hourly limits can be achieved.
- It is uncertain based on the available data if, the proposed daily averages will be able to be achieved. Further discussion and review is needed to determine the particulars in this case, and to examine the differences in the design of this facility and waste stream managed, versus that of BAT facilities permitted in other jurisdictions.

In regards to the current monitoring requirements and averaging periods applied to the Burnaby incinerator, the recommended approach does diverge from that currently in place for the facility for some parameters as summarized in Table 9-24.

Table 9-24: Comparison of Actual and Proposed Daily and ½ Hourly Monitoring Requirements for the Burnaby Incinerator

Parameter	Comparison to Proposed Daily Average Requirements	Comparison to proposed ½ Hourly Average Requirements
TPM	Consistent with current approach based on annual stack testing methods approved by the Regional Manager.	New requirement for CEM with new lower ½ hourly average achieved 97% of the time over an operating year.
CO	New requirement.	Current limit applied over 4-hour rolling average of CEM. Reporting based on ½ hourly averages would be new.
SO ₂	Consistent with current approach based on annual stack testing methods approved by the Regional Manager.	New requirement. Would require CEM.
NO _x as NO ₂	Consistent with current approach which requires reporting based on 24-average of CEM.	New requirement.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 9: Emission Limits and Their Application

Parameter	Comparison to Proposed Daily Average Requirements	Comparison to proposed ½ Hourly Average Requirements
HCl	Consistent with current approach which requires reporting based on 24-average of CEM.	New requirement.
HF	Consistent with current approach based on annual stack testing methods approved by the Regional Manager.	New requirement. Would require CEM. May be omitted should treatment stages for HCl demonstrate that the ELV for HCl is not exceeded.
Organic Matter as CH ₄	NA	NA
TOC	New requirement.	New requirement. Would require CEM.
As	Consistent with current approach based on annual stack testing methods approved by the Regional Manager.	NA
Cd	Consistent with current approach based on annual stack testing methods approved by the Regional Manager.	NA
Cr	Consistent with current approach based on annual stack testing methods approved by the Regional Manager.	NA
Pb	Consistent with current approach based on annual stack testing methods approved by the Regional Manager.	NA
Mercury	Consistent with current approach based on annual stack testing methods approved by the Regional Manager.	NA
Chlorophenols	Consistent with current approach based on annual stack testing methods approved by the Regional Manager.	NA
Chlorobenzenes	Consistent with current approach based on annual stack testing methods approved by the Regional Manager.	NA
PAHs	Consistent with current approach based on annual stack testing methods approved by the Regional Manager.	NA
PCBs	Consistent with current approach based on annual stack testing methods approved by the Regional Manager.	NA
Total PCDD/F TEQ	Consistent with current approach based on annual stack testing methods approved by the Regional Manager.	NA
Opacity	NA	Consistent with current approach, CEM used to determine average over ½ hour averaging period.

Comparison to the Proposed Amendments to the ELVs for the Gold River Power Facility

It is also reasonable to conduct a comparison to the proposed permitted limits for the only other permitted WTE facility in the Province. The proposed amendments to the existing permit for this facility include suggested 1 hr and 24 hour limits for a number of parameters, and thus exhibit greater alignment with the proposed ½ hour and 24 hour emissions limits. Comparing the proposed values for the Gold River facility with the suggested ½ hourly and 24 hour averages for application in BC indicates that:

- The proposed ELV for total particulate matter for the Gold River plant of 15 is higher in value than the proposed ½ hourly limit. However, the proposed ELV appears like it would have to be achieved 100% of the time over the operating year, in comparison with the proposed value that would have to be achieved 97% of the time over the operating year. The proponent has also proposed ELVs for particulate less than 10 µm and less than 2.5 µm; however, the proposed limits in both cases are above the proposed daily and ½ hour averages for TPM in the proposed provincial limits.
- The proposed ELV for CO is higher than the daily average proposed for the province but less than the proposed ½ hour limit.
- The proposed ELV for SO₂ is just a little less than the daily average proposed for the province and is less than the proposed ½ hour limit.
- Hourly and daily averages are proposed for NO_x, HCl and HF emissions, with the proposed ELVs being somewhat less than the proposed ½ hourly and daily averages proposed for the province, with the exception of the daily average for HCl which is over twice the proposed provincial value. Follow-up would be required to determine why the proposed facility may not be able to meet the 10 mg/Rm³ daily average limit.
- Proposed Gold River ELVs for trace heavy metals are in all cases equal to or less than the existing values for BC, and would be in general there should be no issue in meeting the proposed daily average values for the individual and grouped metals.
- Proposed Gold River ELVs for the range of organic parameters are in most cases equal to or less than the proposed daily averages for BC, with the exception of dioxins and furans where the proposed ELV is slightly higher than the proposed daily average for the province.

Generally it would appear that the proposed revisions to the emissions criteria for MSW incineration in BC would be consistent with the proposed approach for the new Gold River Power WTE facility, however, some modifications may be necessary for the ELVs for a few parameters.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 9: Emission Limits and Their Application

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10 MANAGEMENT OF WTE RESIDUES

By using thermal treatment (mass burn incineration or alternative approaches) to manage municipal solid waste, a large reduction in the original volume and mass of the waste is achieved.

Conventional mass burn combustion results in the production of solid residuals which need to be managed in an appropriate manner. Conventional WTE combustion residues include:

- **Bottom Ash** – composed of post-combustion solid waste including the ash, non-combustible residuals (such as metal, rock, concrete, some types of glass) and potentially residuals of incomplete combustion (carbon)
- **Fly Ash** – composed of particulate matter produced by waste incineration in the combustion chamber and removed from the emission stream by the air pollution control (APC) system. Dry particulate control systems such as baghouses and electrostatic precipitators collect fly ash which can be managed as a dry solid waste
- **APC residues** – composed of spent or waste by-products from the APC system, such as reagents used in acid gas scrubbing (typically lime), activated carbon (used in dioxin/furan and heavy metal removal) and scrubber sludge (if a wet acid gas control system is used). APC residues typically include the fly ash the APC system has removed and may be dry solid waste or contain some moisture from semi-dry or wet APC systems.

Historically, fly ash was collected separately from APC residues but in most modern WTE facilities, it is collected and mixed together with APC residues. These are both referred to collectively as APC residues in the remainder of this section.

This subsection of the report discusses the regulatory framework governing incinerator residue management in Europe and North America and the current and emerging management strategies being used worldwide to manage bottom ash and APC residues. First, however, the typical composition (and the factors affecting the composition) of bottom ash and APC residues are discussed in order to better understand each residue stream.

10.1 Composition of Residues

The following subsections discuss the typical composition of bottom ash and APC residues from municipal solid waste mass burn facilities, and the composition of residues from gasification facilities.

10.1.1 Bottom Ash

Bottom ash is the mineral material left after the combustion of the waste. Bottom ash from a MSW incineration facility is a heterogeneous mixture of slag, metals, ceramics, glass, unburned organic matter and other non-combustible inorganic materials. Bottom ash consists mainly of silicates, oxides and carbonates. Typically, bottom ash makes up approximately 20 – 25% by weight or 5 to 10% by

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 10: Management of WTE Residues

volume of the original waste.^[244] At most incineration facilities, bottom ash is mechanically collected, cooled (sometimes water quenched then drained), and mechanically, magnetically or electrically screened to recover recyclable metals. The remaining residue is typically disposed of at a landfill. It may also be incorporated into an alternate beneficial use, such as a construction aggregate substitute, assuming it has the appropriate physical properties and chemical composition and that it meets regulatory requirements in the applicable jurisdiction.^[245]

Table 10-1 illustrates the typical composition of bottom ash produced by MSW mass burn incinerators. The composition of the bottom ash is directly dependant on the in-feed waste composition, as described in Section 9.1.3. While organic constituents are typically destroyed by the high temperature and extended residence time found in a WTE facility, inorganic constituents are not destroyed and typically are found in the bottom ash.

Table 10-1: Composition of Bottom Ash from MSW Incineration in Various Jurisdictions

Parameter	Units	Typical German Values ^[246]	Hyks and Astrup (2009) ^[247]	Worldwide Range Found in MSWI Bottom Ash ^[248]
TOC	% by mass	<0.1-<2.2	N. Def.	N. Def.
Loss on Ignition	% by mass	<3	N. Def.	N. Def.
PCDD/PCDF	ng I-TEQ/kg	<3.3-<15	N. Def.	N. Def..
Aluminum	mg/kg	N. Def.	N. Def.	22,000 – 73,000
Antimony	mg/kg	N. Def.	10 – 432	10 – 430
Arsenic	mg/kg	1 – 20	5 – 189	0.1 – 190
Barium	mg/kg	N. Def.	400 -3,720	400 -3,000
Cadmium	mg/kg	1 – 25	1.0 – 40	0.3 – 70
Calcium	mg/kg	N. Def.	N. Def.	370 – 123,000
Chlorine	mg/kg	N. Def.	1,420 – 8,400	800 – 4,200
Chromium	mg/kg	100 – 1,000	230 – 3.100	23 – 3,200
Copper	mg/kg	500 – 5,000	900 – 8,240	190 – 8,200
Iron	mg/kg	N. Def.	N. Def.	4,100 – 150,000
Lead	mg/kg	300 – 6,000	1,270 – 5,400	100 – 13,700
Magnesium	mg/kg	N. Def.	N. Def.	400 – 26,000
Manganese	mg/kg	N. Def.	N. Def.	80 – 2,400
Mercury	mg/kg	0.01 – 0.5	<0.01 – 7.8	0.02 – 8
Molybdenum	mg/kg	N. Def.	2.5 – 51	2 – 280

²⁴⁴ AECOM report, 2009

²⁴⁵ AECOM report, 2009

²⁴⁶ UBA. 2001. Draft of a German Report with basic information for a BREF-Documents "Waste Incineration". Umweltbundesamt

²⁴⁷ Hyks and Astrup. 2009. Influence of operational conditions, waste input and ageing on contaminant leaching from waste incinerator bottom ash: A full-scale study. In *Chemosphere* 76 (2009) 1178-1184

²⁴⁸ Sabbas, *et al.* 2003. Management of municipal waste incineration residues. In *Waste Management* 23 (2003) 61-88

Parameter	Units	Typical German Values ^[246]	Hyks and Astrup (2009) ^[247]	Worldwide Range Found in MSWI Bottom Ash ^[248]
Nickel	mg/kg	30 – 600	60 – 650	7 – 4,200
Potassium	mg/kg	N. Def.	N. Def.	750 – 16,000
Silicon	mg/kg	N. Def.	N. Def.	91,000 – 308,000
Sodium	mg/kg	N. Def.	N. Def.	2,800 – 42,000
Sulphur	mg/kg	N. Def.	1,300 – 11,080	1,000 – 5,000
Vanadium	mg/kg	N. Def.	36 – 122	20 – 120
Zinc	mg/kg	30 – 10,000	2,370 – 6,200	610 – 7,800

NOTES:

N. Def. – Not Defined

Bottom ash from typical mass-burn facilities combusting MSW is typically classified as a non-hazardous waste. The constituents in the ash, including those listed in Table 9-1, are typically not leachable using the standard test methods, indicating contaminants are not mobile and are chemically/mechanically bound in the ash matrix. As a result of this non-hazardous classification, the disposal of bottom ash in a landfill or subsequent beneficial use is facilitated.

Bottom ash may be also produced at facilities that incinerate or co-incinerate refuse derived fuels and the composition of the bottom ash will vary with the waste type. For example, facilities that burn wood waste derived from forest products processing residues, biosolids or land clearing wastes will have lower concentrations of constituents of concern (such as trace metals) in their bottom ash than typically found in MSW bottom ash. As a result of the variability, it is important for new mass burn facilities to anticipate the quality of the bottom ash and plan on management of the ash in accordance with the ash characteristics. Additional discussion on the classification of ash is provided in Section 9.2 below.

10.1.2 APC Residues

APC residues are the residues from the APC system and other parts of incinerators where flue gas passes (i.e., superheater, economizer). APC residues are usually a mixture of lime, fly ash and carbon and are normally removed from the emission gases by a fabric filter baghouse and/or electrostatic precipitator.

APC residues contain high levels of soluble salts, particularly chlorides, heavy metals such as cadmium, lead, copper and zinc, and trace levels of organic pollutants such as dioxins and furans. The high levels of soluble, and therefore leachable, chlorides primarily originate from polyvinyl chloride (PVC) found in municipal solid waste. The composition of fly ash and APC residue is directly related to the composition of the in-feed to the incinerator. Wastes with higher concentrations of trace metals and refractory organic compounds will produce fly ash with higher concentrations of

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 10: Management of WTE Residues

these constituents of concern. Typically, APC residues make up approximately 2 – 4% by weight of the original waste.^[249]

Compared to bottom ash, APC residues are often classified and managed as hazardous wastes. APC residues typically contain elevated concentrations of heavy metals compared to bottom ash. Fly ash and APC residues are hazardous wastes because of mechanical and chemical behavior of the constituents in the emission. Fine particulate present in the flue gas has been found to form a nucleus on which volatilized metals evolved in the combustion zone condense^[250]. These have been found to be water soluble and therefore are more leachable than the heavy metals found in bottom ash. As with bottom ash, the composition of APC residues and of fly ash will vary depending on the composition of the waste in the incinerator in-feed.

The primary environmental concerns associated with APC residues are the leaching of:

- **Easily soluble salts such as Cl and Na.** Although these substances are not usually associated with toxicity to humans, they may have a negative effect on ecosystems and drinking water resources.
- **Heavy metals such as Cd, Cr, Cu, Hg, Ni, Pb, and Zn.** Heavy metals and trace elements can be present in concentrations high enough to be potentially harmful to humans and ecosystems.
- **Dioxins/Furans.** Although not usually highly leachable (due to low aqueous solubility), these substances are considered toxic.

All jurisdictions surveyed have the choice of either treating APC residues as hazardous waste, or applying treatment to render the fly-ash as non-hazardous and suitable for disposal in a sanitary landfill.

The following table (Table 10-2) presents the typical composition of APC residues resulting from the thermal treatment of MSW. The values were taken from three separate scientific studies.^{[251] [252]}

Table 10-2: Typical Composition of APC Residues Resulting from the Combustion of MSW

Parameter	Units	Burnaby MSW APC Residue Average (2004)	Quina (2005)	Hjelmar (1996b)	International Ash Working Group (IAWG) (1997)
Si	g/kg	25.9	45 – 83	57 – 98	36 – 120
Al	g/kg	13.8	12 – 40	17 – 46	12 – 83
Fe	g/kg	5.8	4 – 16	3.6 – 18	2.6 – 71
Ca	g/kg	258.8	92 – 361	170 – 290	110 – 350
Mg	g/kg	5.6	nd	7.1 – 12	5.1 – 14

²⁴⁹ Algonquin Power Energy from Waste Facility Fact Sheet, <http://www.peelregion.ca/pw/waste/facilities/algonquin-power.htm#ash>

²⁵⁰ Chiang, K.Y. Wang, K. S. , Lin, F. L, Toxicology Environmental Chemistry 64, 1997

²⁵¹ Evaluation of GVRD Municipal Incinerator Ash as a Supplementary Cementing Material in Concrete, AMEC, 2004

²⁵² Treatment and use of air pollution control residues from MSW incineration: An overview. Quina *et al.* 2007

Parameter	Units	Burnaby MSW APC Residue Average (2004)	Quina (2005)	Hjelmar (1996b)	International Ash Working Group (IAWG) (1997)
K	g/kg	23.1	23 – 30	27 – 40	5.9 – 40
Na	g/kg	29.6	22 – 33	12 – 19	7.6 – 29
Cl	g/kg	200.6	101 – 138	92 – 220	62 – 380
P	g/kg	3	nd	1.7 – 4.6	1.7 – 4.6
Mn	g/kg	0.3	nd	0.3 – 0.7	0.2 – 0.9
As	mg/kg	232	nd	40 – 260	18 – 530
Ba	mg/kg	392	nd	310 – 1,400	51 – 14,000
Cd	mg/kg	253	49 – 87	140 – 300	140 – 300
Co	mg/kg	20	nd	4 – 15	4 – 300
Cr	mg/kg	900	72 – 259	150 – 570	73 – 570
Cu	mg/kg	878	440 – 648	450 – 1,100	16 – 1,700
Hg	mg/kg	-	9 – 16	9.3 – 44	0.1 – 51
Mo	mg/kg	23.5	nd	9.3 – 20	9.3 – 29
Ni	mg/kg	43.7	45 – 132	20 – 63	19 – 710
Pb	mg/kg	4,417	1,495 – 2,453	4,000 – 6,500	2,500 – 10,000
Se	mg/kg	–	nd	8.2 – 16	0.7 – 29
Sn	mg/kg	750	nd	620 – 780	620 – 1,400
Zn	mg/kg	18,800	4,308 – 6,574	12,000 – 19,000	7,000 – 20,000
PAH	µg/kg	–	nd	18 – 5,600	30
PCB	µg/kg	–	nd	<40	nd
PCDD	µg/kg	–	nd	0.7 – 1,000	0.7 – 32
PCDF	µg/kg	–	nd	1.4 – 370	1.4 – 73
TCDD	eqv	–	nd	0.8 – 2	0.8 – 2
TOC	g/kg	–	10	6 – 9	6 – 9

NOTES:

– Not reported or not available at the time this report was prepared.
nd – Not detected

This table indicates that the composition of the fly ash/APC residue from the Metro Vancouver Burnaby Municipal Solid Waste Incinerator is generally similar to the APC residue composition at other facilities operating in the EU.

10.1.3 Factors Affecting Ash Composition

There are several factors that affect the physical and chemical characteristics of bottom ash and APC residues resulting from the thermal treatment of MSW. The following are considered to be the primary factors affecting the quality of ash produced by MSW WTE facilities:

- The composition of waste being incinerated will affect ash quality. MSW is heterogeneous, with specific composition varying by jurisdiction. General ranges of composition have been developed but actual composition is specific to the catchment or service area for the WTE facility. Waste diversion strategies specific to a region can reduce the concentration of recyclable materials such as paper, metals and plastic, leaving the MSW with higher proportions of non-recoverable wastes including metallic and organic wastes. Diversion and source removal of potentially harmful constituents from the MSW, such as batteries, lead-based products, household hazardous wastes and fluorescent lamp tubes, prior to combustion will have the benefit of improving the quality of the bottom ash and APC residues.
- Front-end processing of the waste will also affect ash composition. Typically, MSW is deposited in a large bunker at the facility where it can be homogenized manually before entering the in-feed system. Some facilities also conduct source separation at this stage. Removal of potentially harmful constituents and homogenization of the waste will improve the quality of bottom ash and APC residues.
- Type of APC system being used will have an effect on fly ash and APC residue quality and quantity.
- Operating conditions of the incinerator will affect the quality of bottom ash and the flue gas and subsequently the APC residues. The physical geometry of the combustion zone will affect the residence time at the temperature required for complete combustion and the velocity of the flue gas through the incinerator and APC works. Also, upset operating conditions, such as start-up or shut down, or failure of some portion of the incineration or APC system, will affect ash quality. Steady operating conditions will produce a better quality ash.

Each jurisdiction will have a slightly different composition of MSW being incinerated; therefore the range of ash composition provided above is illustrative of the types and magnitude of the constituents of concern that may be contained in the ash.

10.1.4 Gasification Residue Management

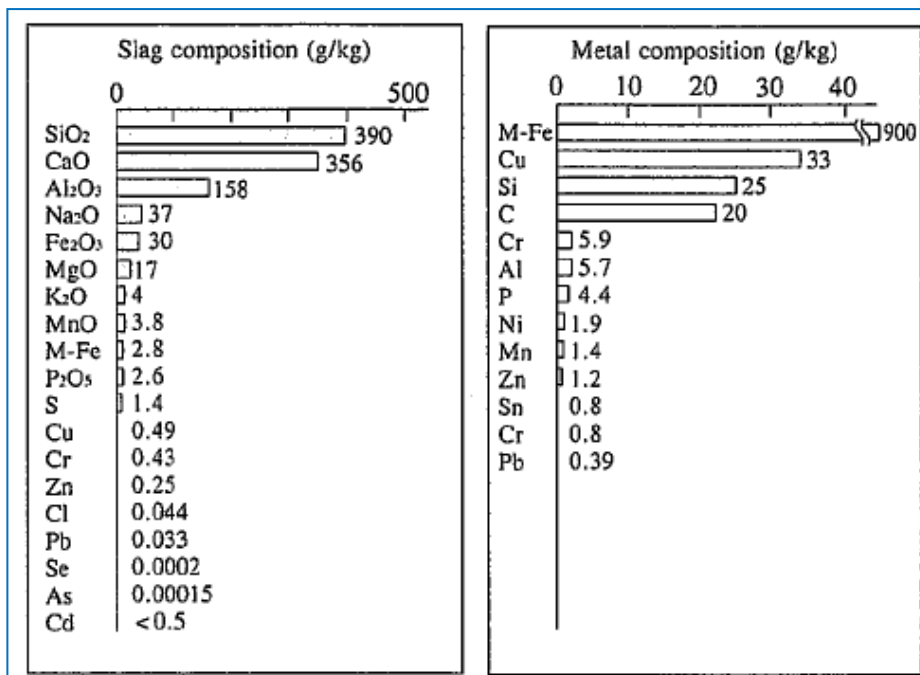
The types and composition of the solid residues produced by gasification facilities treating MSW depends on the particular gasification technology being considered as well as the composition of the waste being treated. The following paragraphs discuss the solid residues arising from the Nippon Steel “Direct Melting System” and the Thermoselect processes, as both processes have reasonable documentation on the solid residues produced. It should be noted that both of these technologies are considered high temperature gasifiers and produce residues which have different characteristics from those produced by other gasification technologies where high temperatures are not reached. Nippon Steel and Thermoselect are discussed because they are both more commercially proven

than other gasification approaches and as documentation was readily available that discussed solid residue management for these processes.

10.1.4.1 Nippon Steel “Direct Melting System”

The Nippon Steel “Direct Melting System” produces slag and metal (the metal is separated from the slag via a magnetic separator) from the melting furnace and produces fly ash from the combustion chamber, gas cooler and bagfilter/electrostatic precipitator. The slag and metal produced and recovered from the melting furnace are recycled (in Japan). The following figure (Figure 10-3) presents the composition of the slag and metal recovered from the melting furnace. It should be mentioned that the data presented comes from one of Nippon Steel’s demonstration facilities and the waste being treated was not MSW but a variety of different waste materials.^[253]

Figure 10-1: Composition of Slag and Metal from Nippon Steel “Direct Melting” Furnace



Taking advantage of its low impurity content and good homogeneity the slag is normally sold by facilities as a substitute for natural sand. It is used as fine aggregate for asphalt paving mixtures. The metal recovered from the melting furnace has a very high iron content and good homogeneity and is often sold to be used in construction machinery counterweights. The fly ash produced is treated chemically to render it harmless and is then disposed of via landfill.

²⁵³ Nippon Steel Technical Report No. 70. July 1996. Research and Development of Direct Melting Process for Municipal Solid Waste

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 10: Management of WTE Residues

10.1.4.2 Thermoselect

The Thermoselect process produces a wider array of solid residues than does the Nippon Steel process. Approximately 22 – 30% (by weight) of the original materials are left over as solid residues following the Thermoselect process.^[254] In the Thermoselect process slag and metal is produced by the high temperature reactor. These materials are separated magnetically. Other solid residues result from synthesis gas cleaning and process water treatment. The following table (Table 10-3) illustrates the types of solid residues resulting from the Thermoselect process and how they are utilized or recycled.^[255]

Table 10-3: Residues from Thermoselect Process

Residue	% of Total Input (by weight)	Potential Usage
Mineral granulate	20 – 25%	Concrete, sand blasting, road construction
Metals	1 – 3%	Metal industry
Sulphur	0.2% – 0.3%	Chemical industry, sulphuric acid production
Salt Residues	1%	Chemical industry, additive for metal industry, aluminum recycling, filling materials in salt mines
Metal precipitation products of water purification (primarily Zn, some Pb, Cd, Hg)	0.2 – 0.3%	Zinc recycling

In addition to the solid residues listed in the table, additional residues would result if the syngas was combusted for electricity generation on site. These residues would include fly ash residues from the baghouse as well as residues associated with flue gas treatment (sodium sulphide). That said, the residual fly ash is often fed into the gasifier and recycled in that manner.^[256]

The following table (Table 10-4) shows the composition of mineral granulate that was produced by the Thermoselect process (Karlsruhe, Germany).^[257]

Table 10-4: Composition of Mineral Granulate Produced by Thermoselect Process (Karlsruhe, Germany)

Component	Unit	Composition
Water	% by weight	5 – 10
Bulk Density	Kg/m ³	Approximately 1,400
Ignition Loss	%TS	0.1
Carbon, total	%TS	<0.01

²⁵⁴ W.F.M Hesseling. 2002. Case Study ThermoSelect Facility Karlsruhe

²⁵⁵ Interstate Waste Technology. 2006. Thermoselect Technology an Overview. Presented to the Delaware Solid Waste Management Technical Working Group January 10, 2006

²⁵⁶ Thermoselect. 2005. Thermoselect Plant and Process Description

²⁵⁷ W.F.M Hesseling. 2002. Case Study ThermoSelect Facility Karlsruhe

Component	Unit	Composition
Al	%TS	3.4
Ca	%TS	8.9
Fe	%TS	9.3
Si	%TS	24.5
Cd	mg/kg TS	<6.0
Hg	mg/kg TS	<2.6
Sb	mg/kg TS	18
As	mg/kg TS	<3.7
Pb	mg/kg TS	202
Cr	mg/kg TS	2,670
Cu	mg/kg TS	2,240
Mn	mg/kg TS	1,470
Ni	mg/kg TS	265
Sn	mg/kg TS	93
Zn	mg/kg TS	890

10.2 Ash Management Regulations in Europe and North America

The regulatory environment and thus the methods of managing bottom ash and APC residues, varies across jurisdictions. The following subsections discuss the current regulatory framework in Europe and North America.

10.2.1.1 European Union

In the EU, there is no legislation that directly regulates the utilization of MSW incinerator bottom ash. That said much of the current legislation does provide guidance on the use of bottom ash from incinerators. APC residues on the other hand are classified as hazardous waste in the EU and management of this residue stream is directly regulated. The following sections discuss the EU regulations and how they impact the management of both bottom ash and fly ash.

EU Waste Incineration Directive (WID)

The following list outlines the guidance concerning the handling of bottom ash and APC residues as provided in the WID:

- Emphasis on the recycling of residues (on-site methods of recycling preferred but not required). Local regulatory authorities should require operators to keep records of such recycling and report in accordance with standard permit conditions.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices
Final Report
Section 10: Management of WTE Residues

- Total organic carbon should be limited to 3% while loss on ignition should be approximately 5%.
- Fugitive dust releases from dusty wastes (including bottom ash) should be prevented by using best available technology equipment. Although containers are not needed in all circumstances (as damp storage may be sufficient for bottom ashes), new plants are expected to provide for ash storage within a building and in an area of controlled drainage.
- Bottom ash and APC residues (fly ash) should not be mixed together.
- Particular attention should be paid to APC residues which should be held in bags or bulk containers.
- Appropriate physical and chemical testing must be performed on all residues to determine the pollution potential of the residues prior to disposal or recycling. Analysis should be carried out to determine the total soluble fraction and the heavy metals content of this soluble fraction.

The process of revising the WID started in 2008 and the revisions may impact the allowable emissions levels from incinerators as well as the composition of residues. The revised directive is expected to be released in 2012. The new BREF for residue management is planned for 2010 – 2012.

EU Landfill Directive (LFD)

If the WTE residues are to be disposed via landfill, the management of these residues is governed by the direction found in the Landfill Directive (LFD). The LFD governs the landfilling of waste in Europe and was officially adopted in 1999. The LFD aims “to provide for measures, procedures and guidance to prevent or reduce as far as possible the negative effects on the environment...from the landfilling of waste.”^[258]

Further clarification to the LFD was given in 2002 by a Council Decision which set out waste acceptance criteria for waste that can be accepted at various types of landfills^[259]. The LFD distinguishes between the main classes of landfills:

- Landfills for inert waste
- Landfills for non-hazardous waste
- Landfills for hazardous waste
- Underground storage.

Each of the three types of landfills has waste acceptance criteria which set out the types of waste that the landfill can accept and the characteristics of that waste. The acceptance criteria include performing standard leachability tests to quantify mobile toxic constituents.

Fly ash and APC residues with heavy metals and dioxins/furans are classified as hazardous wastes and because of excessive leaching of salts; these residues are not accepted for disposal at hazardous waste landfills without pre-treatment. Consequently, they must either be placed in

²⁵⁸ EU landfill directive

²⁵⁹ Management of municipal solid waste incineration residues. Sabbas, *et al.* 2001

underground storage or stabilized prior to disposal at a hazardous waste landfill. The methods used to stabilize fly ash and APC residues are discussed further in this report.^[260]

Bottom ash does not contain the same concentrations of harmful substances and can therefore be disposed of at a non-hazardous waste landfill or used for an alternative beneficial use.

The LFD is a minimum directive, and EU member states are allowed to set stricter national criteria for waste acceptance at their own landfills.

Thematic Strategy on the Prevention and Recycling of Waste

The strategy on the prevention and recycling of waste was released in December 2005. “The aim of the strategy is to reduce the negative impact on the environment that is caused by waste throughout its life-span, from production to disposal, via recycling. This approach means that every item of waste is seen not only as a source of pollution to be reduced, but also as a potential resource to be exploited.”^[261]

Although no specific issues related to ash management are mentioned, an introduction of life-cycle thinking into waste management regulation may potentially have a large impact on the way residue management is evaluated and discussed in the EU.

EU Statutory Order on POP

The EU Statutory Order on Persistent Organic Pollutants^[262] (POPs) regulates the management of waste containing persistent organic compounds, including dioxins and furans (15 µg/kg), PCB, and a variety of organic pesticide products (each 50 mg/kg). This directive requires that waste containing POPs must be managed in such a way as to destroy or irreversibly transform the POPs by physico-chemical treatment, incineration on land or use as a fuel to generate energy. With respect to APC residue, physio-chemical pretreatment includes stabilization prior to disposal in a landfill.

10.2.1.2 European Union Member States

The following subsections outline the regulatory framework in place for the management of residues in various European Member States.

Netherlands

In the Netherlands, the management of waste is regulated through the framework of the Landelijk Afvalbeheer Plan (Federal Waste Management Plan) or simply LAP. The LAP sets out standards for the use of both APC residues and bottom ash as follows:

- Bottom ash and fly ash must be collected and managed separately. No mixing is permitted.

²⁶⁰ Air pollution control residues from waste incineration: Current UK situation and assessment of alternative technologies. Rani, *et al.* 2007

²⁶¹ http://europa.eu/legislation_summaries/environment/sustainable_development/l28168_en.htm

²⁶² Regulation (EC) No 850/2004 of the European Parliament and of the Council of 29 April 2004 on persistent organic pollutants and amending Directive 79/117/EEC

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices
Final Report
Section 10: Management of WTE Residues

- Close to 100% must be utilized (a total utilization rate of 90% is considered the minimum standard for bottom ash + fly ash + APC residues).
- For bottom ash, utilization in large scale controlled embankments is considered the minimum option for utilization.

The Dutch Waste Incineration Directive also sets out compositional limits for bottom ash reflective of WTE facility performance, namely that the loss of ignition must be lower than 5%.

In the Netherlands, another piece of legislation called the Building Materials Decree (which came into force in 1998) sets the rules toward the environmentally safe utilization of building materials (such as incinerator bottom ash). The Decree stipulates the increase of 21 pollutants to a maximum of 1% over a 100 year period. As bottom ash is often used as a building material aggregate, it is subject to the Decree.

If bottom ash is to be used in accordance with the Decree, the following requirements must be met:

- The quantity of bottom ash used must be a minimum of 10,000 tonnes in foundations
- The quantity of bottom ash used must be a minimum of 100,000 tonnes in embankments
- A triple liner has to be used to cover the bottom ash
- Leaching quality of the bottom ash has to be monitored.

The limits set out in the EU LFD are implemented in Dutch legislation.^[263]

United Kingdom

In the UK, solid residues from municipal waste incinerators including bottom ash and air pollution control residues are considered controlled wastes. APC residues are classified as hazardous waste at the point they are generated at WTE facilities.

Ash residues are regulated by the UK's Environment Agency under the *Environmental Protection Act*. In the UK, solid residues are disposed of or recovered in a number of ways:

- Bottom ash is generally landfilled, used as landfill cover, or processed to produce an aggregate for use in highway sub-bases and embankments.
- APC residues are also landfilled or used in licensed waste treatment plants to neutralise and solidify other hazardous wastes.

Operators of landfills and treatment plants accepting air pollution control residues or bottom ash require a permit from the Environmental Agency (a waste management license). This permit must include conditions designed to protect the environment and human health.^{[264],[265]}

²⁶³ Management of APC residues from WTE Plants. ISWA. 2008

²⁶⁴ Solid Residues from Municipal Waste Incinerators in England and Wales. Environment Agency. May 2002

²⁶⁵ Management of Bottom Ash from WTE Plants. An overview of management options and treatment methods

Denmark

Being densely populated, Denmark seeks to avoid landfilling of wastes. Consequently, since 1997 landfilling of combustible wastes has been banned in favor of incineration. To further facilitate this, the Danish government has established a statutory order which allows the incinerator bottom ash to be utilized as a substitute construction material. Depending on the leaching properties, the ash is classified into three categories. Materials belonging to Category 1 may be utilized freely, while materials in Category 3 may only be utilized in certain projects. Category 2 is an intermediate class.

10.2.1.3 United States

In the United States, the management of residual ash from WTE facilities is regulated at both the federal and state level.

Federal

At the federal level, ash generated at WTE facilities is regulated under Subtitle C of the US *Resource Conservation and Recovery Act* (RCRA). Under Subtitle C, operators of WTE facilities must determine whether ash generated is hazardous based on the Toxicity Characteristic (TC) provision. Ash first becomes subject to this hazardous waste determination at the point that the ash leaves the “resource recovery facility”, defined as the combustion building (including connected APC equipment). Ash that falls under the regulation includes bottom ash, APC residues (fly ash) or any combination of the two (i.e., the common practice in the United States is to combine bottom ash and fly ash and dispose of the material as a combined ash stream).^[266]

The TC is one of four characteristics described in Subtitle C by which hazardous waste is identified. It is determined by either testing using the Toxicity Characteristic Leaching Procedure (TCLP) or by using knowledge of the combustion process to determine whether ash would exhibit the TC. Typically, ash that fails the TC, leaches lead or cadmium above levels of concern. In addition to the TCLP, alternative leaching procedures are sometimes used as specified by a state (e.g., California requires the California Waste Extraction Text) and some states may require total metal and organic analysis and fish bio assays.^{[267],[268]}

The following table (Table 10-5) presents a list of TC contaminants and their associated regulatory levels.

²⁶⁶ National Renewable Energy Laboratory. 1999. Beneficial Use and Recycling of Municipal Waste Combustion Residues – A Comprehensive Resource Document

²⁶⁷ Environmental Protection Agency. 2005. 40 CFR Part 270: Determination of Point at Which RCRA Subtitle C Jurisdiction Begins for Municipal Waste Combustion Ash at Waste-to-Energy Facilities

²⁶⁸ National Renewable Energy Laboratory. 1999. Beneficial Use and Recycling of Municipal Waste Combustion Residues – A Comprehensive Resource Document

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 10: Management of WTE Residues

Table 10-5: List of Toxicity Characteristic Contaminants and Regulatory Levels²⁶⁹

Contaminant	Regulatory Level (mg/L)
Arsenic (As)	5.0
Barium (Ba)	100.0
Benzene	0.5
Cadmium (Cd)	1.0
Carbon Tetrachloride	0.5
Chlordane	0.03
Chlorobenzene	100.0
Chloroform	6.0
Chromium (Cr)	5.0
o-Cresol	200.0
m-Cresol	200.0
p-Cresol	200.0
Cresol	200.0
2,4-D	10.0
1,4-Dichlorobenzene	7.5
1,2-Dichloroethane	0.5
1,1-Dichloroethylene	0.7
2,4-Dinitrotoluene	0.13
Endrin	0.02
Heptachlor	0.008
Hexachlorobenzene	0.13
Hexachlorobutadiene	0.5
Hexachloroethane	3.0
Lead (Pb)	5.0
Lindane	0.4
Mercury (Hg)	0.2
Methoxychlor	10.0
Methyl ethyl ketone	200.0
Nitrobenzene	2.0
Pentachlorophenol	100.0
Pyridine	5.0
Selenium (Se)	1.0

²⁶⁹ Environment, Health, and Safety Online. 2009. The EPA TCLP: Toxicity Characteristic Leaching Procedure and Characteristic Wastes (D-codes). Accessed May 24, 2010 from <http://www.ehso.com/cssepa/TCLP.htm>

Contaminant	Regulatory Level (mg/L)
Silver (Ag)	5.0
Tetrachloroethylene	0.7
Toxaphene	0.5
Trichloroethylene	0.5
2,4, 5-Trichlorophenol	400.0
2,4,6-Trichlorophenol	2.0
2,4,5-TP (Silvex)	1.0
Vinyl Chloride	0.2

If the ash is determined to be hazardous waste, it must be handled in compliance with US EPA regulations for hazardous waste management (e.g., disposal via a hazardous waste landfill). Ash that is determined as being non-hazardous can be disposed of at a non-hazardous waste facility (e.g., a Subtitle D landfill) or it can be beneficially used.^[270]

Prior to 1994, it was generally accepted that the ash residue from municipal WTE facilities was exempt from Subtitle C of the RCRA. This changed, however, on May 2, 1994 after a Supreme Court decision stated that although WTE facilities could burn household waste alone or in combination with industrial and commercial wastes and would not be regulated under Subtitle C of the RCRA, the ash generated from these facilities is not exempt from the regulation.^[271]

The following sections describe the regulatory requirements concerning ash management in several US states.

Washington

The Washington State Department of Ecology adopted one of the more stringent regulatory programs for 'special incinerator ash' in 1990. The Washington Administrative Codes (WAC) contain special incinerator ash management and utilization standards (173-306-490). The codes impose numerous requirements and standards, including monitoring and sampling, disposal in specifically designed monofills with prohibition against co-disposal; ash management plans; siting, operational, treatment, closure and post-closure standards; ash utilization standards; and financial assurance.^[272]

The codes require that incinerator ash generators provide annual reports that include the amount of waste incinerated, the amount of bottom ash generated, and the amount of fly ash/scrubber residue generated, the disposal sites for the material, designation of test results (the results of testing bottom

²⁷⁰ Office of Solid Waste, US Environmental Protection Agency. 1995. Guidance for the Sampling and Analysis of Municipal Waste Combustion Ash for the Toxicity Characteristic

²⁷¹ Department of Environmental Protection, Florida, Solid Waste Section. 2001. Guidance for Preparing Municipal Waste-to-Energy Ash Beneficial Use Demonstrations

²⁷² Kim Maree Johannessen. 1996. The regulation of municipal waste incineration ash: A legal review and update. In *Journal of Hazardous Materials* 47 (1996) 383-393

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 10: Management of WTE Residues

ash and fly ash/scrubber residues separately and combined) on representative samples taken each quarter of the year (this may be reduced after the first year of testing). The report must also provide results of testing bottom ash and fly ash separately for dioxins and dibenzofurans on a composite sample made from the eight quarterly samples as well as ambient lead and cadmium samples taken in the air and soil respectively at the property boundary.^[273]

The test results are subjected to the criteria of WAC 173-303-100 (Dangerous Waste Criteria). A waste is designated a dangerous waste if it meets one or more of the dangerous waste criteria listed as toxicity criteria or persistence criteria. Toxicity criteria are determined by either a book designation procedure (if enough information concerning the waste's composition is known) or biological testing methods (e.g., fish, rat bioassays). Persistence criteria are determined by either applying knowledge of the waste or by testing the waste according to WAC 173-303-110. Persistent constituents are substances which are either halogenated organic compounds (HOC) or polycyclic aromatic hydrocarbons (PAH). Depending on the concentration of the persistent substance present in the waste, the waste will be defined as either dangerous or not.^[274]

If ash is classified as a dangerous waste it must be disposed of at a facility which is operating either under a valid permit, or if the facility is located outside of this state, under interim status or a permit issued by United States EPA under 40 CFR Part 270, or under interim status or a permit issued by another state which has been authorized by United States EPA pursuant to 40 CFR Part 271.^[275] If ash is not classified as dangerous waste it must be disposed of at a site which holds a valid permit (ash monofills).

California

In California, regulations require that WTE ash be tested for toxicity prior to disposal. The state requires that for any substance that potentially fall under the RCRA, the use of a Waste Extraction Text (WET) be used for toxicity testing. The WET test is more stringent than the TCLP, and measures both soluble thresholds and total thresholds. The WET test dilutes the waste less, involves a longer extraction period (48 hours vs. 18 hours) and includes the analysis of more parameters of concern.^[276]

10.2.1.4 Canada

In Canada, the handling of residual ash is regulated by each province. The following sections describe the applicable regulations in Ontario and British Columbia.

Ontario

In Ontario, the handling of residues from incinerators that process MSW is governed by Ontario Regulation 347 under the *Environmental Protection Act*. Regulation 347 outlines several

²⁷³ WAC 173-306: Special incinerator ash management standards. 2000

²⁷⁴ WAC 173-303-100: Dangerous waste criteria

²⁷⁵ WAC 173-303-141: Treatment, storage, or disposal of dangerous waste. 2003

²⁷⁶ National Renewable Energy Laboratory. 1999. Beneficial Use and Recycling of Municipal Waste Combustion Residues – A Comprehensive Resource Document

requirements concerning the management of bottom ash and APC residues. The following is an overview of the requirements:

- Fly ash from an incinerator's energy recovery and pollution control system must be handled separately from the burning zone's bottom ash.
- Fly ash must be tested for leachate toxicity if the operator wants to classify the ash as non-hazardous. The testing protocol for leachate toxicity is contained in Ontario Regulation 347 while the sampling procedure and results evaluation procedure is in the ministry's policy publication "Protocol for Sampling and Evaluating Fly Ash from Non-Hazardous Solid Waste Incineration Facilities". Ontario requires application of the TCLP for leachate toxicity similar to the US EPA TL requirements.
- Incinerator operators shall analyze bottom and fly ashes sent to disposal for leachate toxicity and ultimate analysis during performance tests or at the direction of the Director of the Ministry's Environmental Assessment and Approvals Branch.
- Fly ash that is deemed hazardous must be disposed of at a landfill site that is capable of accepting fly ash (i.e., is permitted to accept the waste via a waste certificate of approval).
- Incinerators shall be operated such that the organic content of the bottom ash shall be minimized to the greatest degree possible. A maximum organic content of 5% is generally considered achievable by single chamber incinerators and 10% by multiple chamber incinerators.^[277]

British Columbia

Regulatory Framework

In British Columbia, the management of residual ash from the incineration of MSW is regulated by the British Columbia *Environmental Management Act*^[278] (EMA) and associated enabling Regulations, including the *Waste Discharge Regulation*, the *Contaminated Sites Regulation* and the *Hazardous Waste Regulation*. In general terms in British Columbia, the introduction of waste into the environment must be authorized by a permit issued under the EMA and Regulations. The incineration of municipal waste originating from residential, commercial, institutional, demolition, land clearing or construction sources is identified in Schedule 1 of the *Waste Discharge Regulation*. This means the activity requires authorization from BCMOE for the introduction of waste into the environment. If the waste discharge is governed by a Code of Practice approved by BCMOE, then the operation is exempt from obtaining a permit if the discharge is conducted in a manner consistent with the Code of Practice. For the municipal solid waste incineration sector, there is currently no Code of Practice in place. Requirements specific to the management of bottom ash or APC residues from a MSW incineration facility would be specified in the permit for the incineration facility and/or in the authorization for the landfill site. Solid Waste Management Plans (SWMP) are required for each

²⁷⁷ GUIDELINE A-7 Combustion and Air Pollution Control Requirements for New Municipal Waste Incinerators. Ontario Ministry of the Environment. 2004

²⁷⁸ BC *Environmental Management Act*, SBC 2003, October 23, 2003

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices
Final Report
Section 10: Management of WTE Residues

Regional District in the province. With respect to the operation of a municipally-owned and operated landfill, the authorization for an approved SWMP is typically in the form of an Operational Certificate (OC). The OC is issued by the Director of Waste Management and may contain conditions in the same manner as a permit. Specific requirements for the management of incinerator ash at a municipal landfill would be found in the Operational Certificate.

The *Hazardous Waste Regulation*^[279] (HWR) under the EMA specifies the requirements for the management of hazardous waste in BC. Wastes are classified as Hazardous Wastes in BC in several ways. The primary classification method is to determine if a waste is classified as a Dangerous Good by the Canadian *Transportation of Dangerous Goods Act*^[280], and if so it would be considered Hazardous Waste. Wastes may also qualify as hazardous wastes if they contain constituents that are considered hazardous or contain Specific Hazardous Wastes, such as asbestos and waste oil. The HWR contains a leachate extraction test to determine if the constituents of concern in the waste are leachable.

Classification of Residues

In BC, residuals such as bottom ash and fly ash produced by the incineration of MSW are characterized by subjecting the ash to the US EPA as Method 1311 Toxicity Characteristic Leaching Procedure (TCLP). TCLP is widely used across North America to determine if a material is leachable and therefore is classified as a hazardous waste.

Where constituents are found to be leachable by the TCLP in concentrations in excess of the Leachate Quality Standards specified in Table 1 of Schedule 4 of the HWR, the waste would be considered to be a leachable toxic waste and would be classified as a Hazardous Waste. Wastes classified as hazardous waste must be managed in accordance with the requirements of the HWR.

Typically, bottom ash has been found to be non-leachable and suitable for alternative, beneficial reuse, such as substitution aggregate in cement manufacture or road base material. Where reuse is not practical, bottom ash can be disposed of in a permitted landfill as waste without extraordinary precautions.

In contrast, APC residue and fly ash from incineration of MSW are typically found to be leachable by TCLP tests. Constituents of concern are typically trace metals entrained in the fly ash, and potentially include residual organic compounds not destroyed by the incineration process. APC or fly ash residues that are leachable must be either stabilized to reduce the leachability to the point at which it can be managed as a non-hazardous waste material, or disposed of at a secure landfill that is licensed to accept hazardous waste.

As described above, the constituents of concern in the fly ash will vary with the composition of the waste being incinerated. A homogeneous solid waste in-feed that has a low concentration of trace metals or hazardous organic compounds, such as wood waste and land clearing debris, is unlikely to produce a leachable fly ash.

²⁷⁹ BC Hazardous Waste Regulation, B.C. Reg. 63, April 1, 2009

²⁸⁰ Canadian *Transportation of Dangerous Goods Act* and Regulations, SOR/2008-34

Financial Security for Ash Disposal Sites

As discussed above, landfills operating in British Columbia are authorized under the EMA by the BC Ministry of Environment. These authorizations contain a variety of operational and monitoring conditions, established on a site-specific basis to ensure the protection of human health and the environment. One of the administrative requirements that can be included in a permit is the provision of financial security by the permit holder.

Financial security is a tool available to the ministry to manage the financial risks associated with the landfill site in the context of the license to operate and ultimately close the landfill. Typically, security is required by the ministry where a potential long-term liability exists with a facility and where adequate funds need to be available to the Province in the event of a default by the operator or to address the operator's inability to manage pollution originating at the landfill. The need for security is identified by the Director of Waste Management as defined by the EMA. Municipal governments are typically exempt from the requirement to post security, but private landfills and landfills managing hazardous waste are often required to post financial security.

Similar principles apply to the management of contaminated sites in BC. The BC Ministry of Environment document, *Protocol 8*^[281], *Security for Contaminated Sites*, provides a basis where the ministry considers the need for establishment of financial security. The requirements are summarized generally in this section and we refer the reader to the protocol(s) for specific details on their application.

The key guiding principles contained in the Protocol for determining the appropriate financial security include:

- Each site presents a unique set of circumstances that must be considered when determining security requirements
- Security is only required for sites that are considered high risk. *Protocol 12*^[282], *Site Risk Classification, Reclassification and Reporting* provides the guidance on the classification of a site as high risk. In brief summary, this determination has its basis in ecological and human health risk assessment, and considers the concentration of contaminants present at the site and the exposure pathway to receptors of concern. Where wastes and contaminants at a site pose a risk to human health or the environment, the requirement for posting financial security is considered appropriate.
- The requirement for security is the responsibility of the Director of Waste Management and any required security is subject to review. Security should be consistent with precedents set by the Ministry for other similar sites and be consistent, equitable and effective.

²⁸¹ Protocol 8 for Contaminated Sites, *Security for Contaminated Sites*, prepared pursuant to Section 64 of the *Environmental Management Act*, BC Ministry of Environment, November 19, 2007

²⁸² Protocol 12 for Contaminated Sites, *Site Risk Classification, Reclassification and Reporting*, prepared pursuant to Section 64 of the *Environmental Management Act*, BC Ministry of Environment, December 4, 2009

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices Final Report Section 10: Management of WTE Residues

Protocol 8 also includes a procedure for determining the value of financial security required. The basis for the security is the estimate of the potential remediation cost necessary to address future remediation of the high risk site, including capital costs, recurring costs, remediation schedule and discount rates for determining net present value. The required financial security is based on the least cost remedial alternative acceptable to the Director and is equal to 100% of the one-time remediation capital costs plus the value of the total management and monitoring cost over the entire planning and remediation period. The Director is to review the security requirements every one to five years.

Specific to the management of fly ash and bottom ash deposited in a permitted landfill facility, financial security may be required of an operator subject to the qualification criteria discussed above. Typically, bottom ash is not considered hazardous and as such is normally incorporated into the landfill without special precautions. Fly ash typically requires stabilization to reduce the leachability of contaminants and is considered to pose a higher risk than bottom ash. If the fly ash is suitably stabilized so it is no longer leachable, it would be deemed to pose no greater risk than the material contained in the landfill. The security required would therefore be consistent the security requirement for other landfills, if any. Unstabilized fly ash would be considered hazardous waste and would trigger a higher financial security for potential future remediation. There are few sites available in BC for the deposition of unstabilized fly ash, even in specifically designed monofill cells.

Given this high degree of variability of site conditions (size of landfill, quantity of ash in proportion to waste being deposited, environmental sensitivity of the site), and whether a site is classified as high risk, it is not possible to provide a single estimate of the value of financial security. Each site and each case must be evaluated, using the BCMOE Protocols, to determine the level of risk, the potential cost to mitigate or remediate the risk and who the responsible party will be. Unit costs for remediation will be higher for smaller landfills than for larger landfills, but the total cost will always be linked to the volume of material required to be remediated. Therefore, it is not technically unreasonable for the security requirement to be linked to volume of material deposited, but this approach may be logistically difficult to administer. Setting a financial security based on the ultimate capacity of the ash deposition site is more practical.

It is also difficult to differentiate between the risk posed by the ash in the landfill and the risk attributed to the other wastes contained therein. Where ash is managed in separate cells, it may be possible to apportion a remediation cost specific to the ash and separate from any financial security requirement for the landfill as a whole.

In summary, the requirement for a financial security must be considered on a case-by-case basis. It is reasonable for the landfill operator and WTE proponent to evaluate the potential risk posed by the deposition of ash in a landfill site and to justify the appropriate level of financial security that should be required by the Director, and have this requirement formally recognized by a legal instrument issued by the province, such as a permit, Solid Waste Management Plan.

10.3 Management of Bottom Ash and APC Residues

Bottom ash and APC residues can be managed in a variety of different ways but these can basically all be grouped into two main methods:

- Safe Disposal
- Alternative Uses (Recycling and Reuse).

Much investigation has been given to finding alternative uses for bottom ash and APC residues to divert these materials from landfill. Depending on the jurisdiction, bottom ash and APC residues are managed in different ways due to local regulations and/or access to appropriate technologies and markets in which to use the material.

10.3.1 Safe Disposal of Ash

There are several ways in which bottom ash and APC residues can be handled to ensure safe disposal.

Because bottom ash does not typically contain high concentrations of hazardous materials and is not typically leachable, it can usually meet regulatory requirements for disposal via a conventional sanitary landfill. Normally, bottom ash is 'aged' to ensure that it is highly stable (exhibited through a decrease in organic content, and fixing of metals) and less likely to leach its contents. Stabilization by ageing of bottom ash is achieved by simply storing the bottom ash for several weeks or months. For example in Germany, bottom ash is stored/aged for a minimum of three months while in the Netherlands it is stored for a minimum of six weeks.^[283]

APC residues typically contain high levels of leachable toxic substances which must be managed as hazardous waste^[284] at a suitably designed and authorized landfill. Pre-treatment of the APC residue may reduce the leachability and reduce the requirements on the landfill site.

Generally speaking, treatment options to ensure safe disposal for bottom and fly ash are based on one or more of the following principles:

- Physical or chemical separation
- Stabilization/solidification
- Thermal treatment.

Table 10-6 provides an overview of the current practices being used to handle ash residues from solid waste incinerators in order to make them suitable for utilization or safe for disposal.

²⁸³ Management of Bottom Ash from WTE Plants. An overview of management options and treatment methods

²⁸⁴ Characteristics, Treatment and Utilization of Residues from Municipal Waste Incineration. H.A. van der Sloot, *et al.* 2001

Table 10-6: Overview of Principles and Methods of Treatment of Ash Residues Resulting from the Thermal Treat of MSW^[285]

Treatment Principle	Examples of Processes and Unit Operations	Bottom Ash	Fly Ash
Separation	▪ Wash and extraction	1	1,2
	▪ Chemical precipitation		1,2
	▪ Crystallization/evaporation		
	▪ Ion exchange		
	▪ Density and particle size based separation	1	2
	▪ Distillation		2
	▪ Electrolysis		
	▪ Electrokinetic separation		
	▪ Magnetic separation	1	
	▪ Eddy-current separation	1	
Stabilization and/or Solidification	▪ Addition of hydraulic binders	1	1,3
	▪ Addition of pore-filling additives	1,2	1
	▪ Chemical stabilization	1	1
Thermal Treatment	▪ Sintering	1	1,3
	▪ Melting/vitrification	1,3	1,3

NOTES:

1 = Part of existing and proven treatment technology

2 = Have shown promising results, may be expected to be included in future treatment systems

3 = Currently under investigation or have been investigated and not found technically and/or economically feasible

10.3.2 Alternative Uses of Bottom Ash

Recent developments have focused on recycling and reusing bottom ash for construction purposes such as use in asphalt, cement bound materials, and pavement concrete. Bottom ash often shares similar physical and chemical characteristics to conventional aggregates used in construction and therefore may be suitable for substitution in some applications.

The main issues regarding the reuse and recycling of bottom ash are the release of harmful contaminants into the environment, and the requirement that the ash material meets specific technical material requirements to ensure that it has similar characteristics to the traditional materials being used for the same purpose.^[286]

²⁸⁵ Kosson, D.S. and van der Sloot, H.A. Integration of Testing Protocols for Evaluation of Contaminant Release from Monolithic and Granular Wastes. In: Waste Materials In Construction – Putting Theory into Practice. Studies in Environmental Science 71. Eds. J.J.J.M. Goumans, G.J. Senden, and H.A. van der Sloot. Elsevier Science Publishers, Amsterdam, 1997, 201-216

²⁸⁶ Characteristics, Treatment and Utilization of Residues from Municipal Waste Incineration. H.A. van der Sloot, *et al.* 2001

In Europe, bottom ash recycling is very common. Bottom ash has been used successfully in Europe as:

- Embankment fill
- Road base material
- Aggregate for asphalt
- Aggregate for concrete building blocks
- Daily cover material for landfills.

The following table (Table 10-7) illustrates how bottom ash is utilized in various countries worldwide and the percent of bottom ash generated in these jurisdictions which is landfilled.^[287]

Table 10-7: Quantity of Bottom Ash Produced and Utilized in Various Countries Worldwide

Country	Primary Type of Utilization	Bottom Ash Landfilled	
		Tonnes	Percent
Belgium	Construction Material	No Data	–
Czech Republic	Landfill construction	12,577	11%
Denmark	Primarily used as granular sub-base for car parking, bicycle paths and paved and un-paved roads, embankments and filler material for land reclamation. ^[288]	15,348	2%
France	Road construction	707,030	23%
Germany	Civil works, Sub-paving applications	868,200	28%
Italy	Civil works, based material for landfill	602,940	80%
Netherlands	Road construction and embankments	150,000	13%
Norway	Landfill construction	95,000	48%
Switzerland	Landfill	600,000	100%
Spain	Road construction	No data	–
Sweden	Civil works and landfill construction	No data	–
UK	Road construction, concrete aggregate	No data	–
USA	Road construction and landfill	No data	90%

Barriers to the utilization of bottom ash^[289] include:

- **Hazardous waste** – a small percentage of MSW bottom ash can be at risk of being classified as hazardous waste due to its high concentration of lead (>0.25%). This risk is directly related to lead concentration in the in-feed waste.
- **Competition from other recyclables** – in some cases there are other less polluted recyclables/materials which can be used for the same purpose.

²⁸⁷ Management of Bottom Ash from WTE Plants. An overview of management options and treatment methods

²⁸⁸ Thomas Astrup. Pretreatment and utilization of waste incineration bottom ashes: Danish experiences. 2007

²⁸⁹ Management of Bottom Ash from WTE Plants. An overview of management options and treatment methods

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 10: Management of WTE Residues

- **Easy access to landfill** – cheap prices for landfill disposal discourages bottom ash utilization (e.g., Germany).
- **Easy access to natural resources** – abundance of cheap gravel and soil acts as a barrier to utilization (e.g., Switzerland) as an aggregate substitute.
- **Export** – possibilities of cheap disposal in landfills/mines of neighbouring countries can hinder usage.
- **Leaching of salts and trace metals** – potential for leaching must be addressed, often via stabilization.
- **Practical barriers** – if a contractor is not aware that bottom ash can be used it will be a barrier, limited amounts of bottom ash is a practical obstacle.
- **Regulatory barriers** – alternative uses of bottom ash are generally more difficult to permit in jurisdictions that are unfamiliar with such uses, and regulatory change may be necessary in order to permit such uses.

10.3.3 Treatment and Alternative Use of APC Residues

Table 10-8 presents an overview of the predominant management strategies currently being used for managing Fly Ash and/or APC residues in various countries around the world.

Table 10-8: Overview of Management Strategies Used for APC Residue in Various Countries^[290]

Country	Management Strategies of Fly Ash and APC Residue
United States	APC residues and bottom ash are mixed at most MSW incineration plants and disposed as a “combined ash”. The most frequent approach used is disposal in landfills which receive only incineration residues (ash monofills).
Canada	Bottom ash is typically non-hazardous and can have beneficial use or is deposited in a municipal landfill without extraordinary precautions. APC residues are disposed in a hazardous waste landfill after treatment or can be stabilized to reduce leachability and then landfilled.
Sweden	APC residues are disposed in secure landfills after treatment.
Denmark	APC residues and fly ash are classified as special hazardous waste and are currently exported. Significant efforts are being spent to develop treatment methods that can guarantee that APC residues can be landfilled in a sustainable way.
Germany	The APC residues are mainly disposed of in underground disposal sites, such as old salt mines.
Netherlands	Flue gas cleaning wastes are disposed temporarily in large sealed bags at a controlled landfill until better options are available. The utilization of APC residues is presently not considered. The re-use of the waste is subject to investigation.

²⁹⁰ Treatment and use of air pollution control residues from MSW incineration: An overview. Quina, *et al.* 2007

Country	Management Strategies of Fly Ash and APC Residue
France	After industrial solidification and stabilization processes based on the properties of hydraulic binders, the waste is stored in confined cavities in a specific landfill (French Class I and II). The high cost of this treatment is encouraging companies to search for alternatives to disposal.
Italy	Various technologies have been proposed, but the most widely adopted is solidification with a variety of hydraulic binders (such as cement and/or lime, blast furnace slag, etc.).
Portugal	APC residues are treated with hydraulic binders (solidification/stabilization method) and landfilled in specific sites (monofills).
Switzerland	APC residues are pre-treated before being landfilled. Some plants with wet flue gas treatment utilize the acid wastewater from the acid scrubber to extract soluble heavy metals, most notably zinc from the fly ash. The treated fly ash is then mixed into the bottom ash and landfilled together with the bottom ash. The filtrate is neutralised, precipitating the metals, and the sludge is dewatered and dried. If the sludge contains more than 15% Zn it may be recovered – but at a cost – in the metallurgical industry. Other plants apply a near neutral extraction and stabilize the remainder with cement. Export to Germany is also an option.
Japan	MSW fly ash and APC residues are considered as hazardous, and before landfill intermediate treatments must be performed, such as melting, solidification with cement, stabilization using chemical agents or extraction with acid or other solvents. Melted slag may be used in road construction and materials solidified or stabilized with cement are usually landfilled.

A large number of possible uses for APC residues have been investigated and these uses can be grouped into four main categories:

- Construction materials (cement, concrete, ceramics, glass and glass-ceramics)
- Geotechnical applications (road pavement, embankments)
- Agriculture (soil amendments)
- Miscellaneous (sorbent, sludge conditioning).^[291]

Of all the options listed, the one with the most promise appears to be the use of fly ash to produce ceramic or glass-ceramic materials.

APC residues have characteristics somewhat comparable with cement. APC residues have been suggested for use as a substitute cement in concrete for construction purposes. However this has proven to be quite technically difficult as it can negatively impact the strength development and settling times even when only 10 – 20% of the cement is substituted. Further the presence of aluminum in the fly ash can result in hydrogen generation which may lead to cracks and disintegration of concrete with APC residues.^[292]

²⁹¹ Ferreira *et al.* 2003. Possible applications for municipal solid waste fly ash. *Journal of Hazardous Materials*. 96 (203), 201-216

²⁹² Management of APC residues from WTE Plants. ISWA. 2008

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices
Final Report
Section 10: Management of WTE Residues

In addition to alternative uses, several components present in fly ash may be recovered and used again. The primary interest is centered on the recovery of salts, acid, gypsum, and metals.^[293]

- **Salts** – salt recovery directly from the residues is possible after water extraction. This has been considered in conjunction with several treatment technologies generating salt containing process water. This technique is in commercial use today.
- **Acid** – the solution from a first scrubber stage of a multi-stage APC setup is essentially concentrated hydrochloric acid. Techniques to recover this acid are in commercial use.
- **Gypsum** – production of gypsum can be achieved based on recovery of gypsum from the scrubber solution from alkaline scrubbers. This technique is in commercial use.
- **Metals** – metals can be recovered using extraction and thermal techniques. This technique is in commercial use.

Several different treatment options have been developed to make APC residues suitable for disposal or for other alternative uses. As discussed previously, these can be broken down into three main treatment types: separation, stabilization/solidification, and thermal treatment. In practice it may be useful to start the treatment with separation techniques (mainly washing or leaching with fluid solutions that are more aggressive than water) followed by thermal treatment or stabilization/solidification methods.

Separation methods are those that allow the removal or extraction of unwanted materials from the residue so that the residue is of higher quality and can be used for other purposes or the unwanted materials can be captured for other uses. Specific examples of separation techniques include washing processes, leaching (for heavy metal removal), electrochemical processes, and thermal treatment (evaporation). Some methodologies are very effective at removing the hazardous substances, and consequently non-hazardous materials can be obtained. Separation processes can also be used as the first step for further treatments. One study stated that the removal of soluble salts is crucial for sustainable treatment of APC Residue and if the APC residue is going to be used for another purpose.^[294]

Solidification/stabilization (S/S) processes are those that use additives or binders in order to physically and/or chemically immobilize hazardous components initially present in the waste. Solidification reduces the mobility of the contaminants found in the APC residue through encapsulation. Stabilization acts to convert the contaminants into less soluble or less toxic forms, with or without solidification. In practice, it is often useful to combine stabilization with solidification in order to further reduce the chances that hazardous materials can leach out of the APC residues. Cements and pozzolanic materials are the most common binders. In Europe, S/S methods are commonly used to treat APC residue due to the low cost of this approach and as this technology is

²⁹³ Management of APC residues from WTE Plants. ISWA. 2008

²⁹⁴ Quina, *et al.* Treatment and use of air pollution control residues from MSW incineration: An overview. Waste Management. 2008

well established. It appears that most of the current research regarding APC residue management involves investigation of solidification with binders, using in particular Portland cement.^[295]

Thermal methods are those that involve the use of high heat to induce physicochemical changes in the APC residues that reduces the volume and potential for leaching from the material while producing a stable and non-hazardous slag.^[296] The thermal option is highly effective at reducing the opportunities for the leaching of hazardous substances from the APC residues, reducing the volume of the material (therefore using less landfill space), and also destroying dioxins/furans which may be present in the residue. Thermal methods can be broken down into three main categories: sintering, vitrification, and melting (or fusion). The main drawback to the thermal treatment of APC residues is the high cost involved. Thermally treated fly ash results in the production of an environmentally stable material for which secondary applications can be found.

Generally speaking, lower costs are associated with the stabilization/solidification methods than with the separation or thermal treatment options.

10.3.4 Ash Management in Canada

In general, bottom ash is suitable for deposition in a permitted landfill or for selective beneficial use as a construction material. APC residue is generally not suitable for reuse given the concentration of hazardous constituents, the difficulty in stabilizing the ash for beneficial use, and the history of managing this ash as a hazardous waste. Typically, APC residue is stabilized then disposed in a designated monocell in a landfill.

As mentioned previously in this report, there are currently seven operating Canadian MSW thermal treatment facilities. Table 10-9 provides an overview of the generated quantity and the utilization/disposal of the bottom ash and fly ash/APC residues produced by these facilities as of 2006. Over 183,000 tonnes of bottom ash and over 26,000 tonnes of fly ash and APC residue were generated in 2006 from the four largest facilities. The average quantity of bottom ash at these facilities was 25% by weight of input material. Fly ash and APC residue combined represented 4% of the input waste. Information on the quantity of ash generated at two of the operating facilities was not available.

²⁹⁵ Quina, *et al.* Treatment and use of air pollution control residues from MSW incineration: An overview. Waste Management. 2008

²⁹⁶ Air pollution control residues from waste incineration: Current UK situation and assessment of alternative technologies. Rani, *et al.* 2007

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 10: Management of WTE Residues

Table 10-9: Generated Quantity and Utilization/Disposal of MSW Bottom Ash and Fly Ash in Canada in 2006

Facility Name	Bottom Ash Produced (Tonnes) 2006	Bottom Ash Utilization/Disposal (%)	Fly Ash/APC Residue Produced (Tonnes) 2006	Fly Ash/APC Residue Management
Metro Vancouver Waste to Energy Facility	46,719	90% landfill cover 10% road base construction (mostly on site landfill some Metro Vancouver properties)	9,860	Stabilization (Wes-Prix process) thus enabling disposal in MSW landfill
Algonquin Power Peel Energy-From-Waste Facility	38,215	74% landfill cover, 24%landfill, 2 % aggregate use	5,647	Stabilized and disposed of at secure landfill in Quebec
L'incinérateur de la Ville de Quebec	86,300	100% Landfilled	10,290	Fly ash decontaminated on site to extract heavy metals and disposed with bottom ash
PEI Energy Systems EFW Facility	12,289	100% Landfilled	683	Hazardous Waste Disposal
Ville de Levis, Incinérateur	N/A	100% Landfilled	N/A	Fly ash decontaminated, Unknown disposal
MRC del Iles de la Madeleine	440	N/A	160	N/A
Wainwright Energy From Waste Facility	N/A	100% Landfill	N/A	N/A
Total	183,963		26,640	

Metro Vancouver WTE Facility

Metro Vancouver's WTE facility located in Burnaby has been in operation since 1988. The facility produces approximately 47,000 tonnes of bottom ash and almost 10,000 tonnes of fly ash each year. Bottom ash from the facility is passed through a resource recovery section to remove metallic residuals. The bottom ash is sampled and analyzed frequently and has consistently been classified as non-hazardous waste. This classification allows beneficial secondary use of the ash as well as allows the deposition of the ash in a municipal solid waste landfill.

Fly ash from the Metro Vancouver facility post- stabilization has been tested for leachability using the TCLP test method. A comparison of these results to a partial list of the HWR Leachate Quality Standards is summarized in Table 10-10 below.^[297] The test results are given in units of milligrams per litre, which is the concentration of the constituents in the liquid extract. The concentration of leachable lead in unstabilized fly ash causes it to be classified as hazardous waste. However, the

²⁹⁷ Pers Com, Mr. Chris Allan, Metro Vancouver, December 2010

leachable lead concentration in the stabilized fly ash is less than the HWR Standards. A reduction in the lead concentration in the MSW in-feed would result in lower lead concentrations in the unstabilized fly ash but such a targeted diversion strategy would be difficult to implement.

Table 10-10: TCLP Results for Metro Vancouver Burnaby MSW Stabilized Fly Ash and APC Residues and BC HWR Leachate Quality Standards (mg/L)

Parameter (in mg/L)	Stabilized Fly Ash TCLP result	BC HWR Leachate Quality Standards
Arsenic	<0.75	2.5
Barium	1.53	100
Boron	0.26	500
Cadmium	<0.05	0.5
Chromium	0.08	5
Lead	0.5	5
Mercury	<0.005	0.1
Silver	<0.5	5.0

Metro Vancouver MSW incinerator fly ash and APC residue is stabilized using the WES-PHix process, a patented stabilization process that reduces the mobility of heavy metals in the ash by creating an insoluble and highly stable metal phosphate mineral. Once treated, the ash is subjected to the Toxicity Characteristic Leaching Procedure (TCLP) test to verify stability in accordance with the HWR requirements. The treated fly ash is then disposed of at a permitted municipal landfill.

Other treatment methods have been examined for the Burnaby incinerator fly ash^[298] but for the most part have been discounted as a result of the chemical unsuitability of the ash for use as a concrete replacement or additive. Generally in comparison with other aggregate materials, fly ash contains elevated concentrations of chloride and hydroxide salts, potentially causing the release of ammonia during concrete batching or inducing accelerated corrosion in embedded reinforcing steel. It may be suitable as an additive in non-critical, non-reinforced concrete products.

Proposed Gold River Power (Formerly Green Island) WTE Facility

It is estimated that the maximum rate of ash discharged from the proposed Gold River Power facility will be 150,000 tonnes, while burning up to 750,000 tonnes of refuse per annum. No viable options are available in the vicinity of the site for beneficial reuse of the bottom ash at this time, and the primary management method would be landfill disposal. It is intended that fly ash/APC residue will be treated similar to the process used at the Burnaby incinerator, where phosphoric acid will be sprayed on the recovered fly ash to reduce pH and to stabilize and/or render heavy metals insoluble in water. This treatment method is intended to fix any potentially harmful elements in the fly ash such that TCLP testing would confirm that the material is non-hazardous and suitable for disposal in a

²⁹⁸ Ibid

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 10: Management of WTE Residues

sanitary landfill. The treated fly ash/APC residue would be combined with the bottom ash from the facility and disposed in a purpose-built ash monofill designed and operated by Covanta.

An application for an authorization to dispose of ash at a monofill facility in the vicinity of the WTE facility was originally submitted on April 24, 2007 and is in the late stages of review by the Ministry. The original application is being amended to reflect the revised nature and volume of ash, as well as proposed leachate handling procedures.

Region of Peel WTE Facility

The Region of Peel uses a WTE facility as part of its integrated waste management system (the facility is privately owned by Algonquin Power). The facility was commissioned in 1992 and the Region is under contract to provide waste to the facility until 2012. The facility handles approximately half of the Region's MSW (approximately 160,000 tonnes annually). In a given year the facility generates approximately 8,000 tonnes of fly ash and about 40,000 tonnes of bottom ash.^[299]

Currently, the fly ash is stabilized on-site and is sent to a secure disposal site in Quebec. Historically, the bottom ash has been used as a landfill cover, has been sent to landfill for disposal and been used as an aggregate in building materials. In 2006, 74% of the bottom ash was used as landfill cover, 24% was sent directly to landfill and 2% was used as an aggregate supplement.^[300]

More recently, potential applications for the bottom ash have been investigated including its use in asphalt, brick, and concrete manufacturing. Currently, the Region of Peel has a supplier agreement with Greenpath Inc., a Mississauga company, to provide bottom ash for use as an aggregate substitute in the manufacture of paving stones and concrete blocks.^[301] The Region of Peel shipped 6,400 tonnes of bottom ash to Greenpath Inc. from April to September 2009.

Proposed Regions of Durham/York WTE Facility

The ash management system for the proposed Durham/York WTE facility project reflects current design for ash management systems in North America. For that reason, a detailed description of the proposed Ash management and treatment system is provided below, in order to provide a full overview of the potential expectations for ash management associated with new facility design.

For each combustion train, a complete residue conveying system will be furnished and installed. From the quench chamber following the stoker, a hydraulically driven ram will push the residue up an inclined draining/drying chute where a low amplitude electromagnetic vibrator mounted on the chute will vibrate the residue. This vibratory motion acts to separate excess water from the residue, which drains back into the quench bath (the quench bath will be designed such that it is capable of using wastewater from other facility operations). The bottom ash containing enough moisture to prevent dusting (15 to 25% by weight) will then fall to a heavy duty vibrating pan conveyor with integral grizzly scalper (coarse screening device) that services all of the boilers. The vibratory

²⁹⁹ GTAA Partners in Project Green – Algonquin Power – By-Product Synergies. 2009

³⁰⁰ 2007 GENIVAR report

³⁰¹ GTAA Partners in Project Green – Algonquin Power – By-Product Synergies. 2009

conveyor/grizzly scalper will remove large materials from the bottom ash before it is transferred by an enclosed inclined conveyor for transport to the residue storage building (the large materials will be collected and then transported independently via front-end loader to the residue storage building).

Within the residue storage building a magnetic drum and a vibratory screen will be used to separate ferrous material from the bottom ash, and an eddy current separator will be used to remove the non-ferrous metal from the bottom ash. After separation, each material will be directed into dedicated storage bunkers that will store four days worth of each material. A front end loader will stack and recast the materials. The front end loader will also load residue trucks inside the residue building that will take the residue to its final disposal location. Similar to waste delivery trucks the residue trucks will enter and exit through two motor operated doors, triggered automatically by inbound and outbound vehicles to open and close as required. To minimize any dust escaping to the environment during the conveying, separating, and truck loading process, the residue building will be totally enclosed and have a filtered ventilation system complete with a filtration unit (baghouse). The ventilation system will also draw air from the grizzly area and along the enclosed conveyor gallery. The residue storage building will not be connected to any other structure to prevent dust from infiltrating other parts of the Facility.

Following appropriate testing to ensure the material is not hazardous as defined and regulated by the Province, the bottom ash will be transported to a licensed landfill facility. At the time of this submission, it is anticipated that the bottom ash will be utilized as daily cover material. Covanta's Research and Development group are continually investigating new and more beneficial uses for this material.

Fly ash will be collected and managed separately from bottom ash.

The fly ash handling system for each combustion train will collect the fly ash from the convection pass, superheater, economizer and the APC system of that train. Fly ash will be collected via intermediate conveyors which will discharge into one of two redundant ash surge bins. The fly ash conveyors will be water and dust proof. Each ash surge bin will feed an ash conditioner/mixer (pugmill) that will combine and thoroughly mix the ash with Portland cement, pozzolan and water to fix any potentially harmful elements in the fly ash. The conditioned fly ash will then be discharged into the first of seven dedicated conditioned fly ash bunkers in the residue building.

Each bunker will hold three days worth of conditioned fly ash. To maintain a consistent and manageable product, the conditioned fly ash will be turned regularly. After three days, the fly ash will be transferred to the adjacent three-day storage bunker. This process will be repeated as required for a total curing period of up to 21 days (three days in each of the seven bunkers). After the fly ash has cured, it will be loaded into transportation vehicles by the front end loader. The conditioned fly ash will be kept separate from the bottom ash in the residue building.

In Ontario, fly ash is designated as hazardous and therefore must be managed in accordance with Ontario regulatory requirements.

10.4 Summary – BAT for Management of Residues

BAT for the management of residues from WTE facilities have been developed by various European Union Member States. The following list summarizes the generally accepted BAT principles:

- The separate management of bottom ash from fly ash and APC residues to avoid contamination of the bottom ash.
- Each type of ash should be assessed for potential for recovery either alone or in combination. It is important to assess the levels of contaminants in bottom ash and fly ash to assess whether separation or mixing is appropriate.
- Ferrous and non-ferrous metals should be recovered from the bottom ash to the extent practical and economically viable.
- If pre-dusting stages are used by the APC system, an assessment of the composition of the fly ash should be carried out to assess whether it may be recovered, either directly or after treatment, rather than disposed of at a secure landfill.
- The treatment of bottom ash (either on or off site) by a suitable combination of:
 - Dry bottom ash treatment with or without ageing
 - Wet bottom ash treatment with or without ageing
 - Thermal treatment, or
 - Screening and crushing.
- Treat APC residues to the extent required to meet the acceptance criteria for the waste management option selected for them (i.e., cement solidification, thermal treatment, acid extraction etc.).

In BC, BAT for the management of MSW incineration ash includes:

- Diversion of undesirable constituents in the MSW stream, such as metals removal wherever possible, to reduce the concentration of the constituents in the residuals.
- Aging of bottom ash to improve chemical stability prior to reuse.
- Reuse of bottom ash as a construction material substitute, such as a concrete or asphalt aggregate, road base material, or intermediate cover material at a landfill. Other possible beneficial reuses should be explored where practical.
- Subjecting APC residues to leachability (TCLP) tests to determine if the ash qualifies as hazardous waste. Ash that is classified as leachable can be managed as hazardous waste at a secure landfill. Stabilized ash that is rendered non-leachable can be re-classified as non-hazardous waste and can then be managed as solid waste. The *BC Hazardous Waste Regulation* specifies the test methods and limits for classifying residue as hazardous waste.
- Stabilization of APC residues from municipal solid waste incineration facilities to reduce leachability is an acceptable management option. Several proprietary stabilization processes have been developed and may be successfully applied to APC residue. It is important to test

the leachability of the stabilized waste using the TCLP test. Materials that contain concentrations less than the leachability standards provided in Table 1 of the HWR are not considered hazardous waste and can then be deposited in a suitably designed monofill at an authorized MSW landfill. Stabilized material that does not meet the HWR leachate standards must be managed as hazardous waste, which in BC requires out-of-province disposal.

- APC residues and fly ash from the incineration of biomass, wood and land clearing wastes and some RDF should also be subjected to the TCLP test. The absence of constituents of concern in these materials entering the thermal treatment facility results in the residue being more likely to pass the leachate criteria and be suitable for landfilling or reuse similar to bottom ash.

In practical terms, bottom ash from the Burnaby incinerator is deposited in a municipal landfill. Fly ash and APC residue is stabilized (as described above) then placed in a municipal landfill.

The separate management of bottom ash from fly ash and APC residues to avoid contamination of the bottom ash may not be a necessary approach in some contexts in BC. Generally, this would be a best practice approach for WTE facilities located in areas that have reasonable access to potential markets for reuse of the bottom ash, but this approach may be impractical for facilities in more isolated locations. Disposal of combined bottom ash and treated APC residue in a suitably designed secure facility and/or stabilization of the combined ash waste would be acceptable option where beneficial reuse of these residues is unfeasible.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 10: Management of WTE Residues

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11 CONCLUSIONS AND RECOMMENDATIONS

Conclusions and recommendations reached following the review of technologies, BAT, BACT and the regulatory approaches in other jurisdictions, and considerations for regulatory change in BC can be summarized as follows:

Conclusions

1. Mass burn incineration continues to be the most common method of thermal treatment for WTE facilities. It is reasonable to anticipate that this technology would be proposed for new WTE facilities contemplated in BC.
2. Other thermal treatment technologies such as gasification, plasma gasification and pyrolysis have historically had certain limitations due to their complexity, difficulty in handling variations in the waste stream (which can be managed by waste pre-treatment), and lower net energy recovery (electricity and heat energy) once in-plant parasitic consumption is accounted for. These factors tend to make these other thermal treatment technologies less viable. However, the industry continues to evolve and facilities that treat a portion of the waste stream are being proposed, developed and commissioned. As more actual performance data is generated, it will be better understood if the limitations of these approaches can be resolved.
3. The 1991 BC Emission Criteria for Municipal Solid Waste Incinerators (1991 BC Criteria) cut off between small and large facilities of 400 kg/hour (equivalent to 9.6 tonnes per day) was put in place to differentiate between small facilities used for remote locations and/or on-site waste management and larger WTE facilities. In Europe WTE operations generally handle an average of 20 to 30 tonnes of MSW per hour (480 to 720 tonnes per day). To-date, various studies indicate that it is difficult for commercial WTE facilities to be economically viable at annual capacities less than 10 tonnes per hour (equivalent to 100,000 tonnes per year actual throughput), unless there is a local economic driver (e.g., high value local market for heat energy, high transportation costs and/or difficult logistics associated with other disposal options). In some jurisdictions (e.g., Ontario) differentiation between large and small facilities results in differentiation of approvals processes (large WTE requires full Environmental Assessment (EA) Screening, small WTE does not) however, in regards to air emissions the same criterion/limits apply regardless of size to all WTE applications except for very small scale research applications. Other jurisdictions (e.g., United States Environmental Protection Agency (US EPA)) apply different criterion/limits for smaller scale WTE approaches. For the purpose of regulating MSW incineration in the BC context, it seems reasonable that the cut-off of 400 kg/h between small and large facilities should be maintained.
4. The 1991 BC Criteria currently include the key substances of concern that would be released from the main stack (point source) of an existing or new WTE facility. The 1991 BC Criteria do not, however, provide limits for speciated total particulate matter in the 10 micron (PM₁₀) and 2.5 micron (PM_{2.5}) size fractions. This approach is consistent with emission limits observed in other jurisdictions evaluated in this report. The value of specifying limits for

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 11: Conclusions and Recommendations

speciated particulate matter has not been demonstrated and thus limits for these parameters have not been identified in the proposed revisions.

5. The 1991 BC Criteria do not consider fugitive emissions including dust, odour, and Volatile Organic Compounds (VOCs).
6. The specification of temperature and retention time in the combustion zone varies between North America and the EU, although generally these jurisdictions define the combustion zone in a similar fashion (measured after the last point of air injection). In North America, a minimum temperature of 1,000°C with a retention time of 1 second is typical. In the EU, the specification is a minimum of 850°C with a retention time of 2 seconds. Operated correctly within the design criteria for the incinerator, both specifications should produce an acceptable quality of emission before entering the APC. Flexibility in specifying these operating parameters should be considered and the appropriate balance of temperature and retention time applied on a facility-specific basis.

In most jurisdictions, guidance on design and operation of WTE facilities is provided including recommendations related to combustion temperature and residence time, and also for other parameters such as combustion air distribution, oxygen availability, operation of APC systems and ash management. In these jurisdictions as in BC, the recommendations are not intended to restrict technology development or to dictate facility design or equipment selection. Alternative designs and operating conditions may be proposed for approval, and considered by the regulatory authority, provided that the systems are designed and operated such that the Emission Limit Values (ELVs) can be achieved. Proponents are expected to provide sufficient technical information to the regulatory authority to justify alternative design and operational parameters. Once approved, these parameters are reflected in the operational permit(s) and/or conditions set out for the facility.

7. The most common and effective air pollution systems applied to WTE facilities are dry/semi dry, wet and semi wet systems. Several types of “end of pipe” air pollution controls have been applied to WTE facilities. The selection of best technology (either BACT or BAT) depends on the nature of the waste, design of the combustion process, flue gas composition and fluctuation, energy supply, energy recovery and a number of other considerations.
8. Modern WTE facilities are capable of achieving substantial emission reduction through the use of emission control technology. Reductions in the contaminants of concern across the air pollution control system (APC) typically range from 90% up to 99.95% through the application of typical APC systems.
9. Management of NO_x can be accomplished through both Selective Non-Catalytic Reduction (SNCR) and Selective Catalytic Reduction (SCR) systems, with economics in the form of direct costs (including reagent and energy consumption) or financial incentives (e.g., tax regimes) playing a role in the decision regarding which system is selected and in how the system is operated. Lower NO_x emissions can regularly be achieved through SCR. With SNCR, the level of NO_x reduction achieved is often linked to immediate economic drivers since increasing quantities of ammonia injection (i.e., use of additional reagent) are required

to achieve lower emission levels. There is also a trade-off with SNCR, as the odour associated with ammonia slippage (stack ammonia releases due to excess ammonia not reacting with NO_x) must be considered.

10. Emission releases from WTE facilities have decreased substantially in the US between 1990 and 2005. SO_x and NO_x have been reduced by 88% and 24% respectively. The reductions have resulted from improvements in thermal treatment technology and operational control, improvements in waste diversion and source separation prior to thermal treatment, and improvements in the design and operation of the APC equipment.
11. The EU Energy Efficiency Equation will be adopted by EU member states by the end of 2010 as a means of differentiating between the energy recovery performance of WTE facilities. In general, the formula can be used for differentiating between energy recovery and disposal within a waste hierarchy. The application of the equation varies between the various EU member states. Further development and definition of the scope and application of the equations is expected. The ministry's Environmental Protection Division operational policy already states a preference for any MSW incineration facilities to meet energy recovery criteria (over disposal, determined using an approach similar the Equation). Therefore, it may be reasonable to modify the Equation to suit a BC context (i.e., modify the energy equivalency factors for electrical and thermal energy as appropriate) as part of future policy development in the Province. However, new WTE facilities in BC may not be able to achieve an energy efficiency of 60% without further development of infrastructure such as district heating that would facilitate the use of heat generated by a WTE facility, recognizing that a high efficiency is difficult to reach through the production of electricity alone.
12. In regards to the use of Refuse Derived Fuel (RDF) as substitute fuel in existing industrial or power generating facilities, the majority of jurisdictions examined in this study use a regulatory approach that combines some facets of the regulatory environment associated with WTE facilities (e.g., many of the same stack emissions limits, the same AAQO requirements) but also tailor these approaches in a more industry specific fashion. Generally, the approach applied to regulate use of RDF in other jurisdictions includes:
 - a) Ensuring that the composition of the RDF is similar in regards to fuel value and general chemical composition to the primary fuel source for the intended combustion facility (e.g., use of cellulosic waste materials in wood-fired boilers).
 - b) Requirement for RDF fuel analysis and comparison to current fuels to determine the potential shift in contaminant mass balance and thus facility emissions.
 - c) The requirement to complete test burns and stack testing to measure and validate predicted shifts in emission quality, if any.
 - d) Application of RDF quality standards, specific to parameters that cannot be reasonably managed in the proposed industrial application (e.g., avoidance of fuels with high PVC content if the control of acid gases is unfeasible).
 - e) Application of the same stack limits applied to WTE facilities, for parameters that are directly associated with fuel quality (e.g., heavy metals, persistent organic pollutants

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 11: Conclusions and Recommendations

(POPs)) but not for emission parameters that are driven largely by the primary purpose and design of the facility (e.g., not including SO_x emissions for cement kilns as these emissions are largely driven by raw material quality).

13. In the EU, it is common for emission limits to be linked to monitoring techniques and corresponding averaging periods. Typically, one-half hour average limits are specified for parameters measured by continuous monitors, whereas daily average limits are specified for parameters measured by periodic monitoring. For some parameters, limits for both continuous and for periodic monitoring are specified. In the US, daily average emission limits are specified regardless of the monitoring method. The industry trend is towards increased use of continuous monitoring devices where they can be correlated as equivalent to periodic monitoring techniques.
14. In the EU, where one-half hour average limits and daily average limits are specified for a parameter, the one-half hour limit is numerically higher than the daily average limit. The dual limits acknowledge that the daily average takes into account the fluctuations in the emission over time, whereas the one-half hour limit more closely represents the maximum allowable discharge concentration over the shorter averaging period.
15. This report highlights the potential use of the dual standards for some parameters as applied in the EU. When comparing the emission limits proposed in this report to the 1991 BC Criteria, the potential monitoring methods applicable for each parameter must be considered. The proposed limits allow for continuous monitoring where appropriate and technically feasible and in general these values are greater than the daily average. The limits also allow for periodic monitoring for parameters that require stack testing and these proposed daily average limits are equal to, or more stringent than, the 1991 BC Criteria. New Ministry of Environment policy indicates that all WTE projects will be required to go through an Environmental Impact Assessment process. This is similar to the approach in jurisdictions such as Ontario, where all WTE projects (above a minimum size limit) are required to go through screening under the *Ontario Environmental Assessment Act*.
16. The BC Hazardous Waste Regulation specifies the methodology for testing leachability of a waste material and determining if it is classified as hazardous waste. Bottom ash, fly ash and APC residue should be subjected to the TCLP test and the ash should then be handled according to the classification.
17. Bottom ash is normally not classified as hazardous waste and it is acceptable practice to deposit bottom ash in a permitted sanitary landfill or for the ash to be utilized for a beneficial use, such as intermediate cover, concrete or asphalt aggregate substitution or road base material. Jurisdictions such as Ontario, recognize that bottom ash from facilities that process non-hazardous municipal waste and that has organic content of less than 10%, is a non-hazardous material and do not require that TCLP testing be carried out on such ash. Fly ash and air pollution control (APC) residue are more likely to contain leachable contaminants and be classified as hazardous waste. Fly ash and APC residue must be disposed of in a secure landfill authorized to receive this class of material. Alternatively, the fly ash/APC residue may be

pre-treated/stabilized to reduce leachability prior to deposition in a municipal sanitary landfill site. There is limited opportunity for beneficial use of fly ash and APC residues in BC, even when stabilized, at the present time.

18. The Waste to Energy sector continues to evolve with the advent of new incineration and new pollution control equipment technology and the further advances in municipal waste diversion and separation technologies. Regulatory agencies including Ontario Ministry of the Environment and the US EPA have either recently revised or are considering revisions to current regulations and criteria. The BC Ministry of Environment should take into account both the technical and regulatory advances underway in comparable jurisdictions when developing revised guidelines.

Recommendations

1. The 1991 BC Criteria for municipal solid waste incineration should be updated to reflect advancements in thermal treatment and pollution control technology and standards applied in other jurisdictions. A table summarizing the recommended emission limits is provided at the end of this section.
2. It is recommended that the Waste Discharge Regulation (WDR) exemption for remote incinerators to accommodate fewer than 100 persons (section 3(7)) remain in place for remote operations. If a facility is serving over 100 persons and is processing less than 400 kg/hr of municipal solid waste, site specific emission limits should be authorized by the Ministry. Facilities over the 400 kg/hr capacity limit should be required to meet new revised emission guidelines as set by the Ministry.
3. The design and operation requirements in the 1991 criteria should continue to apply including the recommended minimum incineration temperature of 1,000°C and minimum residence time of 1 second (after final secondary air injection ports). This requirement should be maintained as the default specification; however proponents should be provided an opportunity to seek an alternate temperature/retention time specification that would result in equivalent thermal destruction efficiencies without impacting emission quality. Flexibility in the application of the temperature and retention time specification is possible, as long as the quality of the emission is maintained for a specific facility. A minimum temperature of 850°C with a retention time of 2 seconds could be considered equivalent, depending on the proposed technology. Adjustments to the temperature profile and retention time for a proposed facility should be demonstrated as equivalent by a facility proponent at the application stage, and would be reflected in the approved operating conditions set out for the facility.
4. The potential for fugitive emissions from WTE facilities should be addressed through site specific design considerations such as maintaining appropriate areas of the facility (e.g., receiving and tipping floor) under negative pressure, using indoor facility air for combustion and specific measures for loading, transfer, storage, accidental loss of containment, as well as the handling of auxiliary fuels and reagents for the APC systems. Revisions to the 1991 BC Criteria should address fugitive emissions with references to Best Management Plans, meeting ambient objectives and/or odours at the fence-line or other enforceable criteria.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 11: Conclusions and Recommendations

5. The revised emission limits presented at the end of this section (also as Table 8-21) should be considered by the Ministry as proposed new emission criteria for WTE facilities in BC.
6. The recommended revised emission criteria generally reflect two approaches to setting in-stack emissions limits. The one-half hour limit is intended to be used where the facility uses continuous monitoring techniques. The one-half hour limit generally represents the maximum allowable concentration of a contaminant not to be exceeded at any time. The daily average limit applies when periodic stack sampling is used to characterize the emissions. The daily average limit should be considered to be the default limit where the facility must use periodic sampling to determine compliance or where continuous monitoring methods are not available or practical. Both the daily average and one-half hour limits should apply to parameters for which continuous monitoring is feasible and conducted, and where periodic stack sampling is required.
7. The recommended revised emission criteria for particulate adopts a hybrid approach to emission limit values from other jurisdictions. Where continuous monitoring systems are used, it is proposed that the concentration of total particulate be less than 9 mg/Rm^3 for 97% of the operating period on a 12 month rolling average, and less than 28 mg/Rm^3 for 100% of the operating period on a 12 month rolling average. Where continuous monitoring systems for particulate are used, opacity monitoring may not be necessary as a compliance parameter unless the continuous monitoring system is not functioning. During this scenario, opacity monitoring can be used as a temporary surrogate until the continuous monitoring system for particulate is reinstated.
8. The recommended revised emission criteria for metals lead (Pb), arsenic (As) and chromium (Cr) should be set as the sum of the three metals as determined by periodic sampling with the ELV being set at 64 ug/Rm^3 .
9. Where a non-MSW thermal treatment facility intends to substitute fuel with RDF, or C&D waste, the facility should be required to meet these revised WTE emission criteria for parameters that are directly associated with fuel quality, such as trace heavy metals and persistent organic pollutants. For particulate emissions, the facility could be required to meet new applicable guidelines (for biomass boilers the Ministry may set new limits of 35 mg/m^3 for facilities ranging in size from 3 to 39 MWh, and 20 mg/m^3 for facilities of 40 MWh and larger). The facility should still meet their permitted emission parameters that are established based on the primary purpose and design of the facility, such as SO_x , CO and NO_x . The range of permitted emission parameters that are established based on the primary purpose and design of the facility will vary as appropriate between specific types of existing industrial installations. This approach is permissive by allowing fuel substitution to occur but also protective by requiring compliance with the appropriate, more stringent, limits for potentially harmful contaminants related to the substituted fuel.
10. Generally, the approach applied to regulate use of RDF in BC should be similar to that used in other jurisdictions, including application of the following sequence of steps during the permitting process:

- a) Ensuring that the composition of the RDF is similar in regards to fuel value and general chemical composition to the primary fuel source for the intended combustion facility (e.g., use of cellulosic waste materials in wood-fired boilers).
- b) Requiring RDF fuel analysis and comparison to current fuels within the applications to use RDF, along with analysis that identifies the potential shift in contaminant mass balance and thus facility emissions.
- c) For use of dissimilar fuels and/or use of RDF where there is some potential for more significant shifts in emissions or concern regarding the degree of emissions shift demonstrated through desk top analysis, in addition to the fuel tests/analysis there should be a requirement to complete test burns and stack testing to measure and validate predicted shifts in emission quality.
- d) Development and application of RDF quality standards and specifications, specific to parameters that cannot be reasonably managed in the proposed industrial application (e.g., avoidance of fuels with high PVC content if the control of acid gases is unfeasible). This would include development of a definition for various fractions of sorted MSW and construction and demolition waste, for example defining what constitutes 'clean' versus 'contaminated' wood waste suitable for use as a substitute fuel for wood waste boilers.
- e) Application of the same stack limits applied to WTE facilities, for parameters that are directly associated with fuel quality (e.g., heavy metals, POPs) but not for emission parameters that are driven largely by the primary purpose and design of the facility (e.g., not including SO_x emissions for cement kilns as these emissions are largely driven by raw material quality). For those parameters that are driven largely by the primary purpose and design of the facility, facility specific ELVs will be determined and applied, potentially resulting in some adjustment to the ELVs for these parameters as set out in the operating permit.

The above represent preliminary recommendations. Further study is required to determine the appropriate RDF fuel quality specifications applicable in BC, and to determine the approach to stack emissions that would be most applicable to each of the major sectors (pulp mill boilers, lime kilns, cement kilns) that would represent industrial users of RDF in BC. The Province should consider development of specific regulatory instruments to address RDF composition (similar to other jurisdictions that regulate RDF composition for various applications) and use as a fuel alternative.

- 11. Dispersion modelling should be conducted to assess risks associated with the location and potential operation of a new WTE facility. Modelling results should show in all cases that AAQOs established or accepted by the Ministry would be not be exceeded with a wide margin of safety for all conceivable modes of operation including upsets.
- 12. Potential effluent discharges from a WTE facility originating from process wastewater (associated wet flue gas treatment), originating from bottom ash storage, or from other process wastewater streams (boiler feed water, sanitary wastewater, storm water (either

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices

Final Report

Section 11: Conclusions and Recommendations

contaminated or clean) or used cooling water should be authorized as part of the Solid Waste Management Plan or under a waste discharge permit with limits determined on a site specific basis.

13. The current approach in BC used for leachability testing of bottom ash, fly ash and APC residues is consistent with other jurisdictions. Testing the leachability of the ash continues to be critical in the decision process for reuse and /or disposal of the bottom ash and APC residues. The TCLP leachate extraction test prescribed in the BC HWR is a suitable test method and widely accepted. Bottom ash found to be non-leachable is not hazardous waste and can have some beneficial use or can be deposited in a permitted landfill. APC residue from MSW treatment systems will likely be leachable and require stabilization prior to disposal in a landfill or should be managed as hazardous waste.
14. Separate handling of bottom ash and APC residues represents best practice in order to optimize recovery and/or beneficial use of bottom ash. New incineration technologies should be required to identify the characteristics of the facility residuals. If residuals are determined to have beneficial use characteristics the proponent should demonstrate the associated environmental benefits and liabilities. If beneficial reuse is not practical, consideration for comingling the ash for landfilling, with stabilization as may be necessary, may be permitted.
15. In the development of revised WTE guidelines, BC Ministry of Environment should take into account ongoing technical and regulatory advancements currently evolving in Ontario, the EU and USA.

Table 11-1: Proposed Revisions to Emission Criteria for Municipal Solid Waste Incineration in British Columbia

Contaminant	Concentration Units	RECOMMENDED EMISSION LIMITS				
		C: Continuous P: Periodic ⁽¹⁾	Daily Average	Average Period and Monitoring Method	Half Hourly Average	Average Period and Monitoring Method
Total Particulate Matter (TPM)	mg/Rm ³ @ 11% O ₂	C (P for existing facilities)	9	Existing facilities without CEMS may use the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	9 ⁽²⁾ 28	1/2 hour average as determined by a continuous emissions monitoring system, achieved 97% of the operating period on a 12 month rolling average. 1/2 hour average as determined by a continuous emissions monitoring system, achieved 100% of the operating period on a 12 month rolling average
Carbon Monoxide (CO)	mg/Rm ³ @ 11% O ₂	C	50	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	100	1/2 hour average as determined by a continuous emissions monitoring system
Sulphur Dioxide (SO ₂)	mg/Rm ³ @ 11% O ₂	C	50	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	190	1/2 hour average as determined by a continuous emissions monitoring system
Nitrogen Oxides (NO _x as NO ₂)	mg/Rm ³ @ 11% O ₂	C	190	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	350	1/2 hour average as determined by a continuous emissions monitoring system
Hydrogen Chloride (HCl)	mg/Rm ³ @ 11% O ₂	C	10	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	60	1/2 hour average as determined by a continuous emissions monitoring system
Hydrogen Fluoride (HF)	mg/Rm ³ @ 11% O ₂	P/C	1	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	4	1/2 hour average as determined by a continuous emissions monitoring system ⁽³⁾ .
Total Organic Carbon	mg/Rm ³ @ 11% O ₂	C	10	Calculated as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	20	1/2 hour average as determined by a continuous emissions monitoring system
Arsenic (As)	µg/Rm ³ @ 11% O ₂	P	See Pb, As and Cr group	Calculated as the sum of three metals determined by arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Cadmium (Cd)	µg/Rm ³ @ 11% O ₂	P	7	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Chromium (Cr)	µg/Rm ³ @ 11% O ₂	P	See Pb, As and Cr group	Calculated as the sum of three metals determined by arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Lead (Pb)	µg/Rm ³ @ 11% O ₂	P	See Pb, As and Cr group	Calculated as the sum of three metals determined by arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Sum of Lead (Pb), Arsenic (As), Chromium (Cr)	µg/Rm ³ @ 11% O ₂	P	64	Calculated as the sum of three metals determined by arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Mercury (Hg)	µg/Rm ³ @ 11% O ₂	P or C ⁽⁴⁾	20	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods, or as the arithmetic average of 24 hours of data from a continuous emissions monitoring system.	N.D.	

Contaminant	Concentration Units	RECOMMENDED EMISSION LIMITS				
		C: Continuous P: Periodic ⁽¹⁾	Daily Average	Average Period and Monitoring Method	Half Hourly Average	Average Period and Monitoring Method
Chlorophenols ⁽⁵⁾	µg/Rm ³ @ 11% O ₂	P	1	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Chlorobenzenes ⁽⁵⁾	µg/Rm ³ @ 11% O ₂	P	1	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Polycyclic Aromatic Hydrocarbons ⁽⁵⁾	µg/Rm ³ @ 11% O ₂	P	5	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Polychlorinated Biphenyls ⁽⁵⁾	µg/Rm ³ @ 11% O ₂	P	1	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Total Dioxins and Furans (as PCDD/F TEQ)	ng/Rm ³ @ 11% O ₂	P	0.08	Calculated as the arithmetic average of a minimum three individual stack tests per stack conducted in accordance with standard methods.	N.D.	
Opacity ⁽⁶⁾	%	C (P optional for existing facilities)	N.D.		5	½ hour average from data taken every 10 seconds, measured by a CEMS

NOTES:
Concentration units: Mass per reference cubic metres corrected to 11% oxygen. Reference conditions: 20°C, 101.3 kPa, dry gas
N.D. = Not Defined
⁽¹⁾ Where Periodic stack test measurements (P) are indicated, the daily averaging period applies. For Continuous monitoring (C), the 1/2 hour averaging period applies. P/C indicates both technologies are available; ELV will be linked to sampling method.
⁽²⁾ 97% of the half-hour average values over an annual rolling average will not exceed 9 mg/Rm³. 100% of the half-hour average values will not exceed 28 mg/Rm³.
⁽³⁾ This requirement may be omitted at the discretion of the Regional Manager should treatment stages for HCl demonstrate that the ELV for HCl is not exceeded.
⁽⁴⁾ Daily Average ELV for mercury applies regardless of monitoring method.
⁽⁵⁾ Proponents may be able to demonstrate that monitoring both Total Organic Carbon (TOC) and Total Dioxin and Furans could negate the need to monitor Chlorophenols, Chlorobenzenes, Polycyclic Aromatic Hydrocarbons and Polychlorinated Biphenyls.
⁽⁶⁾ Opacity will not be required for compliance purposes for facilities utilizing continuous particulate monitoring systems. Opacity monitoring is recommended for operational monitoring purposes. However, monitoring opacity can be used as a temporary surrogate for total particulate monitoring in the event a particulate monitoring system failure. Under these circumstances, the ELV of 5% opacity over a ½ hour averaging period should apply.

12 CLOSURE

This report has been prepared for the benefit of BC Ministry of Environment. The report may not be used by any other person or entity without the express written consent of BCMOE and Stantec. Any use of this report by a third party, or any reliance on decisions made based on it, are the responsibility of such third parties. Stantec accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on this report.

Some of the information presented in this report was provided through existing documents and interviews. Although attempts were made, whenever possible, to obtain additional sources of information, Stantec has assumed that the information provided is accurate.

The information and conclusions contained in this report are based upon work undertaken by trained professional and technical staff in accordance with generally accepted engineering and scientific practices current at the time the work was performed. The conclusions and recommendations presented represent the best judgment of Stantec based on the data obtained during the assessment. Conclusions and recommendations presented in this report should not be construed as legal advice.

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices
Final Report

Appendix A: Database of Current Technology Vendors and Thermal Treatment Technologies



APPENDIX A

Database of Current Technology Vendors and Thermal Treatment Technologies



Database of Current Technology Vendors

Type of Technology	Company	Operating Since	Reference Facility(ies)	Size	Website	Comments
Conventional Combustion						
Mass Burn Incineration	Advanced Alternative Energy (AAEC)	n/a	n/a	n/a	www.aaecorp.com/power.html	No reference facilities, claims to be able to treat waste and biomass
Mass Burn Incineration	ATCO Power	n/a	n/a	n/a	www.atcopower.com	No reference facilities, but actively investigating energy from waste
Mass Burn Incineration	Babcock & Wilcox Volund	1997	Billingham, UK	224,000 tpy	www.volund.dk	One of the 4 main suppliers of mass burn technology
Mass Burn Incineration	CNIM	n/a	Thiverval-Grignon-Plaisir, France	2 x 8 t/h + 1 x 14.7 t/h of household waste	www.CNIM.com	DBO
Modular Two Stage Combustion	Consutech Systems LLC	n/a	Iraq	5333 lbs/hr	http://www.consutech.com/	Design and manufacture incineration and APC equipment
Mass Burn Incineration	Covanta	1990	Huntsville, Alabama	625 tpd	www.covantaholding.com/	Operate 41 facilities in the US, 1 Burnaby - utilize Martin GmbH tech
Modular Two Stage Combustion	Enerwaste	2005	Egegik, Alaska	3.5 tpd	www.enerwaste.com	Also provide a MCS (mass burn type) for pre-processed garbage
Mass Burn Incineration	Fisia Babcock Environment GmbH	2005	Affaldscenter Århus, Denmark	17.5 tph	http://www.fisia-babcock.com/	One of the 4 main suppliers of mass burn technology
Mass Burn Incineration	JFE	2003	Hirano Plant, Japan	900 tpd	www.jfe-eng.co.jp/en	
Fluidized Bed Incineration	JFE	2006	Banpoo WTE Plant, Thailand	100 tpd	www.jfe-eng.co.jp/en	
Mass Burn Incineration	KAB TAKUMA GmbH	2003	Salzbergen, Germany	90,000 tpy	http://www.kab-takuma.com/	
Mass Burn Incineration	Martin GmbH	1999	Neunkirchen, Germany	408 tpd	http://www.martingmbh.de/index.php	One of the four main suppliers of mass burn technology
Mass Burn Incineration	Naanovo Energy Inc.	March 2010	The Gambia	n/a	www.naanovo.com	14 MW facility. Not sure as to the status.
Mass Burn Incineration	Seghers Keppel Technology Group	n/a	Beveren, Belgium	2 x 319 tpd	www.keppelseghers.com	
Mass Burn Incineration	Standardkessel Baumgarte	2007	MSZ 3 Moscow, Russia	330,000 tpy	http://www.standardkessel-baumgarte.com/	Five reference facilities located on their website.
	Steinmuller	n/a	n/a	n/a	http://www.steinmuller.co.za/default.asp?fid=0&sid=24&L=1	Mechanical engineers
Mass Burn Incineration	TPS Termiska	1992	Greve-in-Chianti, Italy	67,000 tpy	www.tps.se/subpage.aspx?MS=14839,15014	
Mass Burn Incineration	Veolia Environmental Services	2003	Hampshire, UK	90,000 tpy	www.VeoliaES.com	More than 80 plants worldwide
Mass Burn Incineration	Von Roll Nova	2007	Issy-les-Moulineaux (Paris), France	460,000 tpy	http://www.aee-vonrollnova.ch	One of the four main suppliers of mass burn technology
Mass Burn Incineration	Wheelabrator Technologies Inc.	1985	Baltimore	2,000 tpd	www.wheelabratortechnologies.com	Operates 21 facilities in the US
Mass Burn Incineration	Wulff Energy and Environmental Systems	n/a	n/a	n/a	http://www.wulff-hamburg.de	Boiler, combustion and drier technologies

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices
Final Report

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Type of Technology	Company	Operating Since	Reference Facility(ies)	Size	Website	Comments
Gasification						
Gasification	Ambient Eco Group	2002	n/a	75,000 to 250,000 tpy	-	
Gasification	City Clean 2000 Inc.	n/a	n/a	n/a	http://cityclean2000.com/	
Gasification	Coaltec Energy	n/a	Carterville, Illinois	Test Facility	www.coaltecenergy.com	
Gasification and Pyrolysis	Compact Power	2002	Bristol, UK	8,000 tpy	-	
Gasification	Ebara (two different technologies)	2002	Kawaguchi City Asahi Clean Centre, Japan	125,400 tpy	www.ebara.co.jp/en/	
Gasification	Emery Energy Company	n/a	Salt Lake City, Utah (Pilot Plant)	25 tpd	www.emeryenergy.com	
Gasification	Energos	1998	Ranheim, Norway	10,000 tpy	www.energ.co.uk/energy_from_waste	
Gasification	Energy Products of Idaho	1989	Tacoma, Washington	317 tpd	www.energyproducts.com	
Gasification	EnerTech Environmental	1997 – 2000 (Demonstration Facility)	Ube City, Japan	18 tpd	www.enertech.com	
Gasification	Envirotherm GmbH	2000	Schwarze Pumpe, Germany	300,000 tpy	http://envirotherm.de/	
Gasification	Eurotech	n/a	Quetzaltenango, Guatemala	n/a	www.eurotecguatemala.com/maineng.htm	
Gasification	Forevergreen Enterprises	Not yet constructed	DeKalb County	n/a	www.fgenterprises.net	
Gasification	Foster Wheeler	1998	Finland	80,000 tpy	www.fwc.com	
Gasification	Full Circle Energy	n/a	n/a	n/a	www.fullcircleanergy.net	
Gasification/Thermal Cracking	GEM America	2000	Tythegston Landfill Site, South Wales	36 tpd	www.gemamericainc.com	
Gasification	Global Energy Inc.	1992	Westfield Development Centre, UK	n/a	www.globalenergyinc.com	
Gasification	Global Energy Solutions Inc	n/a	Japan, Germany, Belgium, Korea, Malta, UK	1-25 tph	www.globalenergychicago.com	
Gasification	Global Warming Prevention Technologies Inc.	n/a	Anchoarge, Alaska; Kuala Lumpur, Malaysia	25 tpd	www.gwpt.com	
Gasification	Greey CTS Inc.	na/	Poland	35,000 tpy	-	
Gasification	Hitachi Zosen	1998	Gifu, Japan	30 tpd	-	
Gasification	ILS Partners	n/a	Germany	22 tpd	www.ils-partners.com	
Gasification	Interstate Waste Technologies (IWT) (uses Thermoselect)	1999	Chiba, Japan	93,000 tpy	www.iwtonline.com	
Gasification	ITI Energy Ltd.	n/a	South West England	72,000 tpy	http://www.iti-energy.com/	
Gasification	JFE	2003	Kakamigahara Plant, Japan	192 tpd	www.jfe-eng.co.jp/en	
Gasification	Karlsruhe Institute of Technology	1993 rotating grate gasifier; 2000 slagging gasifier	Schwarze Pumpe, Germany	700 tpd	www.fzk.de	
Gasification	Lurgi	1993 rotating grate gasifier; 2000 slagging gasifier	Schwarze Pumpe, Germany	700 tpd	www.lurgi.com	
Gasification	Nippon Steel	2002	Akita, Japan	400 tons per day	-	
Gasification	Ntech Environmental	1991	Chung Gung Municipality, Taiwan	27 tpd	www.ntech-environmental.com	
Gasification	OE Gasification	2007	Hapchon, South Korea	20 tpd (MSW)	-	
Gasification	PKA Umwelttechnik GmbH & Co	2001	Aalen, Germany	25,000 tpy	-	

Type of Technology	Company	Operating Since	Reference Facility(ies)	Size	Website	Comments
Gasification	Pyrolyzer	n/a	n/a	n/a	http://pyrolyzerllc.com/	
Gasification	SenreQ International	2002	Barrow, Alaska	27 tpd	-	
Gasification	Sierra Energy Corporation	n/a	n/a	n/a	http://www.sierraenergycorp.com/	
Gasification	SVZ	n/a	n/a	n/a	-	
Gasification	Rentech	1997	Burlington, Vermont	272 tpd	www.silvasgas.com	
Gasification	Terragon Environmental Technologies Inc.	n/a	n/a	Small-scale (Only for remote communities, outposts etc.)	www.terragon.net/MAGS.html	
Gasification	TGE Tech	2007	Tel Aviv	181 tpd	-	
Gasification	Thermogenics, Inc.	n/a	n/a	n/a	www.thermogenics.com	
Gasification	Thermoselect	1999 – 2004	Karlsruhe, Germany	250,000 tpy	www.thermoselect.com	
Gasification	Thide Environmental	2004	Arras, France	50,000 tpy	www.thide.com	
Gasification	Waste-to-Energy	Reference facilities do not process MSW (only biomass)	n/a	n/a	www.wastetoenergy.co.uk	
Gasification	Whitten Group International	1991	Taiwan	8,100 tpy	-	
Plasma Arc Gasification						
Plasma Arc Gasification	AdaptiveNRG	2005	Monterey, Mexico (portable)	33,000 tpy	www.adaptivenrg.com	
Plasma Arc Gasification	AlterNRG (Westinghouse Plasma Technology)	1999	Yoshi, Japan	n/a	www.alternrg.com	
Plasma Arc Gasification	EnviroArcTechnologies	Pilot Plant	Hofors, Sweden	.7 tph	www.enviroarc.com	
	Europlasma	n/a	n/a	n/a	http://www.europlasma.com/	Plasma torches
Plasma Arc Gasification	Geoplasma LLC	1999	Japan, Germany, Belgiu, Korea, Malta, UK	24 tpd	www.geoplasma.com	
Plasma Arc Gasification	Global Environmental Technologies of Ontario Inc.	n/a	n/a	n/a	-	
Plasma Arc Gasification	Green Power Systems	n/a	n/a	n/a	www.greenpowersystems.com	
Plasma Arc Gasification	Hitachi Metals	2003	Utashinai City, Japan	180 tpd	-	
Plasma Arc Gasification	Hi-Tech Enterprise Ltd	n/a	n/a	n/a	-	
Plasma Arc Gasification	InEnTech Chemical (Integrated Environmental Technologies)	n/a	Richland, Washington	22 tpd	www.inentec.com	
Plasma Arc Gasification	MPM Technologies Inc.	1987 – 1988	Libby, Montana (Pilot Plant)	45 tpd; 108 tpd (continuous feed)	www.mpmtech.com	
Plasma Arc Gasification	Peat International Inc	2007	Kaohsiung, Taiwan	9 tpd	www.peat.com	
Plasma Arc Gasification	Plasco Energy Group	2007	Ottawa, Canada	31,100 tpy	www.plasco.com	
Plasma Arc Gasification	Plasma Arc Technologies	n/a	n/a	n/a	www.plasmaarctech.com	
Plasma Arc Gasification	Plasma Environmental Technologies Inc.	No operating facilities.	n/a	n/a	www.plasmaenvironmental.com	
Plasma Arc Gasification	Plasma Waste Recycling	n/a	n/a	n/a	www.plasma-wr.com	
Plasma Arc Gasification	PyroGenesis Inc.	2000	Montreal, Quebec	10 tpd	-	
Plasma Arc Gasification	Recovered Energy Inc. (Westinghouse)	1999	Hitachi plant in Japan	3 tph	www.recoveredenergy.com	

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices
Final Report

Appendix A – Database of Current Technology Vendors

Type of Technology	Company	Operating Since	Reference Facility(ies)	Size	Website	Comments
Plasma Arc Gasification	Rigel Resource Recovery and Conversion Company	2004	Eco-Valley Utashinai Plant, Japan	90,700 tpy	-	
Plasma Arc Gasification	Solena Group	n/a	Europe – no specifics given	n/a	www.solenagroup.com	
Plasma Arc Gasification	Startech Environmental Corporation	2001	Bristol, Connecticut	4.5 tpd (Demonstration Facility)	www.startech.net	
Plasma Arc Gasification	Sun Energy Group LLC	2011	New Orleans	n/a	www.sunenergygrp.com	
Plasma Arc Gasification	US Plasma	n/a	n/a	n/a	-	
Plasma Arc Gasification	Westinghouse Plasma/GeoPlasma	2002	Utashinai & Mihama Mikata, Japan	n/a	www.westinghouse-plasma.com	
Pyrolysis						
Pyrolysis	Balboa Pacific Corporation	n/a	n/a	n/a	www.balboa-pacific.com	
Pyrolysis and Gasification	Brightstar Environmental	2001	Australia	55,000 tpy	-	
Pyrolysis and Gasification	Compact Power	n/a	Avonmouth, UK	Clinical Waste	-	
Pyrolysis	Conrad Industries	1993	Centralia, Washington	Systems designed to process 21 to 65 tpd	www.conradind.com/to_tech_develop.asp	
Pyrolysis	Emerald Power Corporation	n/a	New York City	Commercial Scale Demo	-	
Pyrolysis	ENER-G (acquired Waste Gas Technology)	2002	Sarpsborg 1 Plant, Norway	75,000 tpy	www.energ.co.uk	
Pyrolysis	Entech Renewable Energy	2006	Korea	60 tpd (MSW)	http://www.entech.net.au/ws1/	
Pyrolysis	International Energy Solutions	2004	Romoland, California	16,500 tpy (MSW)	www.wastetopower.com	
Pyrolysis	JND Thermal Process	n/a	Hamburg, Germany	Test Facility	www.jnd.co.uk	
Pyrolysis	Mitsui Babcock	2000	Yame Seibu, Japan	219 tpd	www.doosanbabcock.com	
Pyrolysis	Mitsui R-21	2002	Toyohashi City, Japan	400 tpd	http://www.gec.jp/JSIM_DATA/WASTE/WASTE_3/html/Doc_436.html	
Pyrolysis	Nexus	n/a	France	10-100 tpd	-	
Pyrolysis	North American Power Co.	n/a	Las Vegas Nevada	10 to 68 tpd (Test Facility)	-	
Pyrolysis	Recycled Refuse International	No existing plant	n/a	n/a	www.rcrinternational.com	
Pyrolysis	Splainex Ecosystems Ltd.	n/a	n/a	n/a	www.splainex.com	
Pyrolysis	Takuma	2005	Kakegawa, Japan		www.takuma.co.jp/english/	
Pyrolysis	Technip / Waste Gen	1987	Burgau, Germany	36,200 tpy	www.wastegen.com/alternative.htm	
Pyrolysis amd Gasification	Techtrade	2002	Hamm, Germany	100,000 tpy	www.tech-trade.de/index.html	RDF
Pyrolysis	Thide/Hitachi	2003	Izumo, Japan	63,500 tpy	-	
Pyrolysis	TPF Group (Serpac Pyroflam)	2005	Keflavik, Iceland	41 tpd	www.tpf-bs.be	
Pyrolysis and Gasification	WasteGen (UK)	2000	Hamm, Germany	100,000 tpy	www.wastegen.com/wastegenuk.htm	

Type of Technology	Company	Operating Since	Reference Facility(ies)	Size	Website	Comments
Gasplasma						
Gasplasma	Advanced Plasma Power	n/a	Oxfordshire, Eng.	Small-scale Demonstration Plant	www.advancedplasmapower.com	
Thermal Cracking Technology						
Thermal Cracking Technology	GEM Waste to Energy Inc.	1998	Romsey, England	0.7 tph	www.gemcanadawaste.com/index2.html	
Thermal Oxidation						
Thermal Oxidation	Zeros Technology Holding	No existing plant			www.zerosinc.com	
Waste to Fuel						
Waste to Fuel	BioEngineering Resources (BRI)	2003	Fayetteville, Arkansas	1.3 tpd (Pilot Plant)	www.brienergy.com	
Waste to Fuel	BlueFire Ethanol Inc.	2002	Izumi, Japan		http://bluefireethanol.com/production_plant/	
Waste to Fuel	Changing World Technologies	1999	Philadelphia, PA	Test Facility	www.changingworldtech.com	
Waste to Fuel	Enerkem	2003	Sherbrooke, Quebec	5 tpd (MSW pellets)	www.enerkem.com	
Waste to Fuel	Enerkem (Novera)	To be constructed 2009	Edmonton, Alberta	100,000 tpy	www.enerkem.com	
Waste to Fuel	Genahol Inc.	2007	Lake County, Indiana	30 million gallons ethanol/year	Not constructed yet	
Waste to Fuel	Indiana Ethanol Power	2008	Lake County, Indiana	1,500 tons per day	Not constructed yet	
Waste to Fuel	Masada OxyNol	n/a	n/a	n/a	-	
Waste to Fuel	Power Ecalene Fuels	n/a	n/a	n/a	http://powerecalene.com	Converts syngas to alcohol
Waste to Fuel	Range Fuels Inc.	2008	Denver Colorado	5 oven dried tonnes	www.rangefuels.com	
Other Methodologies						
Kearns Disintegrator	Quantum Solutions Technology Ventures Inc.	1983	Cape Breton Isaldn, Nova Scotia	Prototype	www.gstv.ca/gstv-about.html	
Steam Reforming Plant	Elementa	2007	Sault Ste. Marie	n/a	http://www.elementagroup.com/	



Thermal Treatment Technologies Database

Thermal Treatment Technologies Database (MSW as a Feedstock)

Type of Technology	Company	Operating Since	Reference Facility(ies)	Size	Website	Comments
Conventional Combustion						
Mass Burn Incineration	Advanced Alternative Energy (AAEC)	n/a	n/a	n/a	www.aaecorp.com/power.html	No reference facilities, claims to be able to treat waste and biomass.
Mass Burn Incineration	ATCO Power	n/a	n/a	n/a	www.atcopower.com	No reference facilities, but actively investigating energy from waste.
Mass Burn Incineration	CNIM	n/a	Thiverval-Grignon-Plaisir, France	2 x 8 t/h + 1 x 14.7 t/h of household waste	www.CNIM.com	DBO.
Modular Two Stage Combustion	Consutech Systems LLC	n/a	Iraq	5333 lbs/hr	http://www.consutech.com/	Design and manufacture incineration and APC equipment.
Mass Burn Incineration	Covanta	1990	Huntsville, Alabama	625 tpd	www.covantaholding.com/	Operate 41 facilities in the US, 1 Burnaby - utilize Martin Gmbh tech.
Modular Two Stage Combustion	Enerwaste	2005	Egegik, Alaska	3.5 tpd	www.enerwaste.com	Also provide a MCS (mass burn type) for pre-processed garbage.
Mass Burn Incineration	Fisia Babcock Environment GmbH	2005	Affaldscenter Århus, Denmark	17.5 tph	http://www.fisia-babcock.com/	One of the 4 main suppliers of mass burn technology.
Mass Burn Incineration	JFE	2003	Hirano Plant, Japan	900 tpd	www.ife-eng.co.jp/en	
Fluidized Bed Incineration	JFE	2006	Banpoo WTE Plant, Thailand	100 tpd	www.ife-eng.co.jp/en	
Mass Burn Incineration	KAB TAKUMA GmbH	2003	Salzbergen, Germany	90.000 tpy	http://www.kab-takuma.com/	
Mass Burn Incineration	Martin GmbH	1999	Neunkirchen, Germany	408 tpd	http://www.martingmbh.de/index.php	One of the 4 main suppliers of mass burn technology.
Mass Burn Incineration	Naanovo Energy Inc.	March 2010	The Gambia	n/a	www.naanovo.com	14 MW facility. Not sure as to the status.
Mass Burn Incineration	Seghers Keppel Technology Group	n/a	Beveren, Belgium	2 x 319 tpd	www.keppelseghers.com	
Mass Burn Incineration	Standardkessel Baumgarte	2007	MSZ 3 Moscow, Russia	330,000 tpy	http://www.standardkessel-baumgarte.com/	5 reference facilities located on their website.
	Steinmuller	n/a	n/a	n/a	http://www.steinmuller.co.za/default.asp?fid=0&sid=24&L=1	Mecanical engineers.
Mass Burn Incineration	TPS Termiska	1992	Greve-in-Chianti, Italy	67,000 tpy	www.tps.se/subpage.aspx?MS=14839,15014	
Mass Burn Incineration	Veolia Environmental Services	2003	Hampshire, UK	90,000 tpy	www.VeoliaES.com	More than 80 plants worldwide.
Mass Burn Incineration	Von Roll Nova	2007	Issy-les-Moulineaux (Paris), France	460,000 tpy	http://www.aee-vonrollinova.ch	One of the 4 main suppliers of mass burn technology.
Mass Burn Incineration	Wheelabrator Technologies Inc.	1985	Baltimore	2,000 tpd	www.wheelabratortechnologies.com	Operates 21 facilities in the US..
Mass Burn Incineration	Wulff Energy and Environmental Systems	n/a	n/a	n/a	http://www.wulff-hamburg.de	Boiler, combustion and drier technologies.

Type of Technology	Company	Operating Since	Reference Facility(ies)	Size	Website	Comments
Gasification						
Gasification	Ambient Eco Group	2002	n/a	75,000 to 250,000 tpy		
Gasification	City Clean 2000 Inc.	n/a	n/a	n/a	http://cityclean2000.com/	
Gasification	Coaltec Energy	n/a	Carterville, Illinois	Test Facility	www.coaltecenergy.com	
Gasification and Pyrolysis	Compact Power	2002	Bristol, UK	8,000 tpy		
Gasification	Ebara (two different technologies)	2002	Kawaguchi City Asahi Clean Centre, Japan	125,400 tpy	www.ebara.co.jp/en/	
Gasification	Emery Energy Company	n/a	Salt Lake City, Utah (Pilot Plant)	25 tpd	www.emeryenergy.com	
Gasification	Energos	1998	Ranheim, Norway	10,000 tpy	www.enerq.co.uk/energy_from_waste	
Gasification	Energy Products of Idaho	1989	Tacoma, Washington	317 tpd	www.energyproducts.com	
Gasification	EnerTech Environmental	1997-2000 (Demonstration Facility)	Ube City, Japan	18 tpd	www.enertech.com	
Gasification	Envirotherm GmbH	2000	Schwarze Pumpe, Germany	300,000 tpy	http://envirotherm.de/	
Gasification	Eurotech	n/a	Quetzaltenango, Guatemala	n/a	www.eurotecguatemala.com/maineng.htm	
Gasification	Forevergreen Enterprises	Not yet constructed	DeKalb County	n/a	www.fqenterprises.net	
Gasification	Foster Wheeler	1998	Finland	80,000 tpy	www.fwc.com	
Gasification	Full Circle Energy	n/a	n/a	n/a	www.fullcircleenergy.net	
Gasification / Thermal Cracking	GEM America	2000	Tythegston Landfill Site, South Wales	36 tpd	www.gemamericainc.com	
Gasification	Global Energy Inc.	1992	Westfield Development Centre, UK	n/a	www.globalenergyinc.com	
Gasification	Global Energy Solutions Inc	n/a	Japan, Germany, Belgium, Korea, Malta, UK	1-25 tph	www.globalenergychicago.com	
Gasification	Global Warming Prevention Technologies Inc.	n/a	Anchoarge, Alaska; Kuala Lumpur, Malaysia	25 tpd	www.gwpt.com	
Gasification	Greey CTS Inc.	na/	Poland	35,000 tpy		
Gasification	Hitachi Zosen	1998	Gifu, Japan	30 tpd		
Gasification	ILS Partners	n/a	Germany	22 tpd	www.ils-partners.com	
Gasification	Interstate Waste Technologies (IWT) (uses Thermoselect)	1999	Chiba, Japan	93,000 tpy	www.iwtonline.com	
Gasification	ITI Energy Ltd.	n/a	South West England	72,000 tpy	http://www.iti-energy.com/	
Gasification	JFE	2003	Kakamigahara Plant, Japan	192 tpd	www.jfe-eng.co.jp/en	
Gasification	Karlsruhe Institute of Technology	1993 rotating grate gasifier; 2000 slagging	Schwarze Pumpe, Germany	700 tpd	www.fzk.de	
Gasification	Lurgi	1993 rotating grate gasifier; 2000 slagging	Schwarze Pumpe, Germany	700 tpd	www.lurgi.com	
Gasification	Nippon Steel	2002	Akita, Japan	400 tons per day		
Gasification	Ntech Environmental	1991	Chung Gung Municipality, Taiwan	27 tpd	www.ntech-environmental.com	
Gasification	OE Gasification	2007	Hapchon, South Korea	20 tpd (MSW)		
Gasification	PKA Umwelttechnik GmbH & Co	2001	Aalen, Germany	25,000 tpy		
Gasification	Pyrolyzer	n/a	n/a	n/a	http://pyrolyzerllc.com/	
Gasification	SenreQ International	2002	Barrow, Alaska	27 tpd		
Gasification	Sierra Energy Corporation	n/a	n/a	n/a	http://www.sierraenergycorp.com/	
Gasification	SVZ	n/a	n/a	n/a		
Gasification	Rentech	1997	Burlington, Vermont	272 tpd	www.silvasgas.com	
Gasification	Terragon Environmental Technologies Inc.	n/a	n/a	Small-scale (Only for remote communities, outposts etc.)	www.terragon.net/MAGS.html	
Gasification	TGE Tech	2007	Tel Aviv	181 tpd		
Gasification	Thermogenics, Inc.	n/a	n/a	n/a	www.thermogenics.com	
Gasification	Thermoselect	1999-2004	Karlsruhe, Germany	250,000 tpy	www.thermoselect.com	
Gasification	Thide Environmental	2004	Arras, France	50,000 tpy	www.thide.com	
Gasification	Waste-to-Energy	Reference facilities do not process MSW (only	n/a	n/a	www.wastetoenergy.co.uk	
Gasification	Whitten Group International	1991	Taiwan	8,100 tpy		

Type of Technology	Company	Operating Since	Reference Facility(ies)	Size	Website	Comments
Plasma Arc Gasificaiton						
Plasma Arc Gasification	AdaptiveNRG	2005	Monterey, Mexico (portable)	33,000 tpy	www.adaptivenrg.com	
Plasma Arc Gasification	AlterNRG (Westinghouse Plasma Technology)	1999	Yoshi, Japan	n/a	www.alternrg.com	
Plasma Arc Gasification	EnviroArcTechnologies	Pilot Plant	Hofors, Sweden	.7 tph	www.enviroarc.com	
	Europlasma	n/a	n/a	n/a	http://www.europlasma.com/	Plasma torches.
Plasma Arc Gasification	Geoplasma LLC	1999	Japan, Germany, Belgiu, Korea, Malta, UK	24 tpd	www.geoplasma.com	
Plasma Arc Gasification	Global Environmental Technologies of Ontario Inc.	n/a	n/a	n/a		
Plasma Arc Gasification	Green Power Systems	n/a	n/a	n/a	www.greenpowersystems.com	
Plasma Arc Gasification	Hitachi Metals	2003	Utashinai City, Japan	180 tpd		
Plasma Arc Gasification	Hi-Tech Enterprise Ltd	n/a	n/a	n/a		
Plasma Arc Gasification	InEnTech Chemical (Integrated Environmental Technologies)	n/a	Richland, Washington	22 tpd	www.inentec.com	
Plasma Arc Gasification	MPM Technologies Inc.	1987-1988	Libby, Montana (Pilot Plant)	45 tpd; 108 tpd (continuous feed)	www.mpmtech.com	
Plasma Arc Gasification	Peat International Inc	2007	Kaohsiung, Taiwan	9 tpd	www.peat.com	
Plasma Arc Gasification	Plasco Energy Group	2007	Ottawa, Canada	31,100 tpy	www.plasco.com	
Plasma Arc Gasification	Plasma Arc Technologies	n/a	n/a	n/a	www.plasmaarctech.com	
Plasma Arc Gasification	Plasma Environmental Technologies Inc.	No operating facilities.	n/a	n/a	www.plasmaenvironmental.com	
Plasma Arc Gasification	Plasma Waste Recycling	n/a	n/a	n/a	www.plasma-wr.com	
Plasma Arc Gasification	PyroGenesis Inc.	2000	Montreal, Quebec	10 tpd		
Plasma Arc Gasification	Recovered Energy Inc. (Westinghouse)	1999	Hitachi plant in Japan	3 tph	www.recoveredenergy.com	
Plasma Arc Gasification	Rigel Resource Recovery and Conversion Co	2004	Eco-Valley Utashinai Plant, Japan	90,700 tpy		
Plasma Arc Gasification	Solena Group	n/a	Europe - no specifics given	n/a	www.solenagroup.com	
Plasma Arc Gasification	Startech Environmental Corporation	2001	Bristol, Connecticut	4.5 tpd (Demonstration Facility)	www.startech.net	
Plasma Arc Gasification	Sun Energy Group LLC	2011	New Orleans	n/a	www.sunenergygrp.com	
Plasma Arc Gasification	US Plasma	n/a	n/a	n/a		
Plasma Arc Gasification	Westinghouse Plasma/GeoPlasma	2002	Utashinai & Mihama Mikata, Japan	n/a	www.westinghouse-plasma.com	
Pyrolysis						
Pyrolysis	Balboa Pacific Corporation	n/a	n/a	n/a	www.balboa-pacific.com	
Pyrolysis and Gasification	Brightstar Environmental	2001	Australia	55,000 tpy		
Pyrolysis and Gasification	Compact Power	n/a	Avonmouth, UK	Clinical Waste		
Pyrolysis	Conrad Industries	1993	Centralia, Washington	Systems designed to process 21 to 65 tpd	www.conradind.com/to_tech_develop.asp	
Pyrolysis	Emerald Power Corporation	n/a	New York City	Commercial Scale Demo		
Pyrolysis	ENER-G (acquired Waste Gas Technology)	2002	Sarpsborg 1 Plant, Norway	75,000 tpy	www.energ.co.uk	
Pyrolysis	Entech Renewable Energy	2006	Korea	60 tpd (MSW)	http://www.entech.net.au/ws1/	
Pyrolysis	International Energy Solutions	2004	Romoland, California	16,500 tpy (MSW)	www.wastetopower.com	
Pyrolysis	JND Thermal Process	n/a	Hamburg, Germany	Test Facility	www.jnd.co.uk	
Pyrolysis	Mitsui Babcock	2000	Yame Seibu, Japan	219 tpd	www.doosanbabcock.com	
Pyrolysis	Mitsui R-21	2002	Toyohashi City, Japan	400 tpd	http://www.gec.jp/JSIM_DATA/WASTE/WASTE_3/html/Doc_436.html	
Pyrolysis	Nexus	n/a	France	10-100 tpd		
Pyrolysis	North American Power Co.	n/a	Las Vegas Nevada	10 to 68 tpd (Test Facility)		
Pyrolysis	Recycled Refuse International	No existing plant.	n/a	n/a	www.rcrinternational.com	
Pyrolysis	Splainex Ecosystems Ltd.	n/a	n/a	n/a	www.splainex.com	
Pyrolysis	Takuma	2005	Kakegawa, Japan		www.takuma.co.jp/english/	
Pyrolysis	Technip / Waste Gen	1987	Burgau, Germany	36,200 tpy	www.wastegen.com/alternative.htm	
Pyrolysis amd Gasification	Techtrade	2002	Hamm, Germany	100,000 tpy	www.tech-trade.de/index.html	RDF.
Pyrolysis	Thide/Hitachi	2003	Izumo, Japan	63,500 tpy		
Pyrolysis	TPF Group (Serpac Pyroflam)	2005	Keflavik, Iceland	41 tpd	www.tpf-bs.be	
Pyrolysis and Gasification	WasteGen (UK)	2000	Hamm, Germany	100,000 tpy	www.wastegen.com/wastegenuk.htm	

Type of Technology	Company	Operating Since	Reference Facility(ies)	Size	Website	Comments
Gasplasma						
Gasplasma	Advanced Plasma Power	n/a	Oxfordshire, Eng.	Small-scale Demonstration Plant	www.advancedplasmapower.com	
Thermal Cracking Technology						
Thermal Cracking Technology	GEM Waste to Energy Inc.	1998	Romsey, England	0.7 tph	www.gemcanadawaste.com/index2.html	
Thermal Oxidation						
Thermal Oxidation	Zeros Technology Holding	No existing plant.			www.zerosinc.com	
Waste to Fuel						
Waste to Fuel	BioEngineering Resources (BRI)	2003	Fayetteville, Arkansas	1.3 tpd (Pilot Plant)	www.brienergy.com	
Waste to Fuel	BlueFire Ethanol Inc.	2002	Izumi, Japan		http://bluefireethanol.com/production_plant/	
Waste to Fuel	Changing World Technologies	1999	Philadelphia, PA	Test Facility	www.changingworldtech.com	
Waste to Fuel	Enerkem	2003	Sherbrooke, Quebec	5 tpd (MSW pellets)	www.enerkem.com	
Waste to Fuel	Enerkem (Novera)	To be constructed 2009	Edmonton, Alberta	100,000 tpy	www.enerkem.com	
Waste to Fuel	Genahol Inc.	2007	Lake County, Indiana	30 million gallons ethanol/year	Not constructed yet	
Waste to Fuel	Indiana Ethanol Power	2008	Lake County, Indiana	1,500 tons per day	Not constructed yet	
Waste to Fuel	Masada OxyNol	n/a	n/a	n/a		
Waste to Fuel	Power Ecalene Fuels	n/a	n/a	n/a	http://powerecalene.com	Converts syngas to alcohol.
Waste to Fuel	Range Fuels Inc.	2008	Denver Colorado	5 oven dried tonnes	www.rangefuels.com	
Other Methodologies						
Kearns Disintegrator	Quantum Solutions Technoogy Ventures Inc.	1983	Cape Breton Isaltn, Nova Scotia	Prototype	www.qstv.ca/qstv-about.html	
Steam Reforming Plant	Elementa	2007	Sault Ste. Marie	n/a	http://www.elementagroup.com/	

Waste to Energy

A Technical Review of Municipal Solid Waste Thermal Treatment Practices
Final Report

Appendix B: BC Emission Criteria for MSW Incinerators (June 1991)



APPENDIX B

BC Emission Criteria for MSW Incinerators (June 1991)

Emission Criteria for Municipal Solid Waste Incinerators (June 1991)

FOREWORD

The Emission Criteria for Municipal Solid Waste Incinerators have been developed in consultation with British Columbia stakeholders.

The Executive Committee of the Ministry of Environment approved the release of these criteria on June 17, 1991.

The Environmental Management Branch is responsible for the development of these criteria. The Branch intends to continue development work with British Columbia stakeholders in order that the emission criteria continue to be current and valid. All stakeholders are invited to submit their comments and recommendation for improvements to the Manager, Industry and Business Section.

1 Definitions

"Acid Gases" mean those gaseous contaminants, as listed in [Appendix A](#), which contribute towards the formation of acidic substances in the atmosphere.

"Chlorobenzenes (CBs)" mean those chlorinated benzene compounds listed in [Appendix A](#).

"Chlorophenols (CPs)" mean those chlorinated phenolic compounds listed in [Appendix A](#).

"Incinerator" means any device designed specifically for controlled combustion of wastes, alone or in conjunction with any auxiliary fossil fuel, for the primary purpose of reduction of the volume of the waste charged by destroying the combustible portion therein and/or to recover the available energy from the waste.

Note: Only those incinerators which are designed to burn wastes in a controlled manner, whether in a single-chamber or a multiple-chamber unit, and are capable of meeting the requirements of these Emission Criteria, with or without any emission control devices are to be considered.

"Municipal Solid Waste (MSW)" means municipal refuse which originates from residential, commercial, institutional and industrial sources and includes semi-solid sludges, household hazardous waste and any other substances which are typically disposed of in municipal-type landfills, but does not include biomedical waste.

"Polycyclicaromatic Hydrocarbons (PAHs)" mean those polycyclicaromatic hydrocarbon compounds listed in [Appendix A](#).

"Polychlorinated dibenzo-para-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs)" mean those PCDD and PCDF compounds listed in [Appendix A](#).

"Refuse Derived Fuel (RDF)" means any fuel derived from municipal solid waste.

"Regional Manager" means the "manager" as well as the "district director" as interpreted in the current edition of the *Environmental Management Act*.

" Standard cubic metre (m³) of gas" means the volume of dry gas in cubic metres measured at a pressure of 101.3 kPa and a temperature of 20°C (293.15 K) .

"Toxicity Equivalency Factors (TEFs)" means those factors for Congeners of Concern in a Homologous Group for PCDDs and PCDFs.

2 Applicability

2.1 New or Modified Incinerators

These Emission Criteria are effective from the date of issuance and apply to all new incinerators designed and installed for burning MSW.

2.2 Existing Incinerators

Within five years or less after issuance of these Emission Criteria, the Environmental Management Branch will identify and implement measures for:

1. Phasing out of all older, uncontrolled single chamber incinerators used to burn MSW authorized under the current edition of the *Environmental Management Act* except for equipment which is classified and exempted in the current edition of the Waste Management Regulations of the *Environmental Management Act*; and
2. Modifications of all multiple-chamber, modular and mass burn incinerators used to burn MSW authorized by the current edition of the *Environmental Management Act* but not able to comply with these Emission Criteria.

2.3 Ambient Analysis and Site Specific Emission Limits

Notwithstanding the provisions of these Emission Criteria, no person shall operate a facility to cause emission of contaminants from an incinerator in quantities which may result in adverse impacts on the air quality in the vicinity of the site.

2.3.1 Ambient Air Quality Impact Analysis

An ambient air quality impact analysis shall be one of the major criteria for the selection of a site for an incineration facility. In general, the impacts of emissions from a proposed facility on the ambient air quality shall be determined for the contaminants listed in [Table 1](#) or [Section 3.2.1](#), as applicable to a particular facility. However, depending on the location of the proposed facility, the Regional Manager may require an air quality impact analysis only for certain contaminants selected from [Table 1](#) or [Section 3.2.1](#).

The ground level concentrations of the above contaminants shall be estimated for the worst case scenario by a dispersion model approved by the Regional Manager.

The impact analysis must show that predicted ground level concentrations do not exceed the ambient air quality criteria of the contaminants as stipulated by the Regional Manager.

2.3.2 Site Specific Emission Limits

Depending on the ambient air quality impact analysis results, the Regional Manager may require additional emission control measures for any facility to meet more stringent emission limits than those prescribed herein. The local government, such as a Regional District or Municipality, may also require more restrictive emission limits than those prescribed herein for any facility within its jurisdiction.

3 Emission Limits

3.1 Incinerators with Capacity of Processing over 400 kg/h of Waste

The stack emission limits for various contaminants listed in [Table 1](#) are applicable to the above size incinerators.

3.2 Incinerators with Capacity of Processing over 400kg/h or less of Waste

3.2.1 3.2.1 Emission Limits and Ambient Air Quality Criteria

1. Total particulates concentration in the incinerator stack discharge gas shall not exceed 180 mg/m³, averaged over the approved sampling period, corrected to 11% oxygen.
2. The carbon monoxide concentration in the incinerator stack discharge gas shall not exceed 55 mg/m³, corrected to 11% oxygen, on a 4-hour rolling average basis. In the case of an incinerator burning RDF, the carbon monoxide level in the stack discharge shall not exceed 110 mg/m³, corrected to 11% oxygen on a 4-hour rolling average basis.
3. The opacity of the incinerator stack discharge gas shall not exceed 10% at any time, as measured in accordance with a method approved by the Regional Manager.
4. The of the following gaseous contaminants in the ambient air at locations designated by the Regional Manager shall not exceed:
 - Hydrogen Chloride — 100 µg/m³ (0.5-h average) and 40 µg/m³ (24-h average);
 - Sulphur Dioxide — 450 µg/m³ (1-h average) and 160 µg/m³ (24-h average); and
 - Nitrogen Oxides (measured as Nitrogen Dioxide) — 400 µg/m³ (1-h average) and 200 µg/m³ (24-h average).
5. Depending on the site of the operation, the Regional Manager may at his discretion stipulate additional stack emission limits and/or ambient air quality criteria for any other contaminants.

3.2.2 Limits on Number of Incinerator Units

The installation and simultaneous operation of more than one small capacity (400 kg/h or less of waste processing) incinerator without any post-combustion emission control system at the same facility is not permitted.

3.2.3 Provisions for Emission Control System

Subsequent to the issuance of a Waste Management Permit, the Regional Manager reserves the right to require, at a later date, further control of emissions from an operating incinerator on the basis of an evaluation of the incinerator performance, monitoring data, and any other relevant information. It is recommended that provisions should be made for adequate space and other necessities at the initial design stage of the facility.

4 Incinerator and Emission Control System Design and Operation Requirements

To minimize emission of contaminants from an incinerator, the required design and operation parameters for the equipment as outlined below and summarized in [Table 2](#), shall be followed. The incinerator design and operation parameters listed in [Table 2](#) are applicable to all sizes of incinerators. The emission control system parameters will apply to all incinerators equipped with such systems.

These requirements are based on currently available information and may be revised at a future date, if deemed necessary. Any alternative system of different design, which is operated outside the required parameters, will be acceptable as long as it can be demonstrated that such a system can meet all other requirements of the Emission Criteria. These requirements do not preclude development of any new technology.

4.1 Minimum Incineration Temperature and Residence Time

The incinerator shall be designed, equipped and operated in such a manner that a minimum temperature of 1000°C is maintained in the final combustion zone, at the fully mixed height after the final introduction of combustion air.

The incinerator design must provide for a minimum residence time of 1 second for the combustion gases at 1000°C at the said location during normal operation.

The residence time is to be calculated from the point where most of the combustion has been completed and the incineration temperature fully developed.

In multi-chamber incinerators the residence time is calculated from the secondary burner(s) flame front or final secondary air injection point(s).

In an incinerator where the furnace is one continuous space, such as in spreader stoker and single chamber mass burning equipment, the location of the complete combustion and fully developed temperature shall be determined by an overall design review.

It is recommended that new incinerators be designed conservatively to provide the combustion gases a capability to attain at least 1.2 seconds of residence time at a temperature of 1000°C at the above location.

4.2 Primary Air

The incinerator shall be designed to ensure that an adequate quantity of primary combustion air is distributed properly inside the initial combustion zone to promote good contact between the waste and the air. The design features shall also include the capability to control and adjust both the air flow rate and its distribution to minimize quenching of the combustion reaction and entrainment of particles, as well as to compensate for irregular waste loading on the grate.

4.3 Secondary Air

The incinerator shall be designed for adequate air supply through properly located injection ports to provide sufficient turbulence and mixing of the reactants in the final combustion zone. The location and design of the air injection ports shall ensure good penetration and coverage of furnace cross-section under all flow conditions.

4.4 Auxiliary Burner(s)

The incinerator shall be equipped with auxiliary burner(s) of adequate heat capacity to be used during start-up, shutdown, upset conditions, when burning marginally combustible waste, and at any other time as necessary to maintain the minimum incineration temperature. The auxiliary burner(s) shall be designed such that the minimum combustion zone temperature of 1000°C can be maintained for at least 15 minutes without any waste feeding to the unit. The firing of the auxiliary burner(s) and the supply of combustion air shall be modulated automatically to maintain the required minimum combustion zone temperature.

4.5 Oxygen Level in Flue Gas

To maintain adequate availability of combustion air in the incinerator, the combustion air supply system shall be designed to maintain the oxygen content in the flue gas leaving the unit within the prescribed range.

4.6 Turndown Restrictions

The incinerator shall be designed to meet the minimum requirements of temperature, residence time, combustion air supply, and oxygen level in the flue gas over the recommended range of the waste feed load.

4.7 Maximum Carbon Monoxide Level in Flue Gas

The recommended maximum CO concentration of 55 mg/m³ corrected to 11% O₂ (4-h rolling average) in the incinerator flue gas shall be used as the operating target. Any excursion of CO concentration to twice the above specified level shall require adjustment of operating parameters until the normal combustion conditions are restored.

4.8 Emission Control Systems

The temperature of the flue gas at the outlet of the emission control equipment used for simultaneous removal of acid gases and particulates, or at the inlet of a separate particulates control device, shall not exceed 140°C.

This limit of 140°C temperature requirement does not preclude the use of alternate emission control systems, which may necessitate a higher flue gas discharge temperature, provided it can be demonstrated that the stipulated emission limits in [Table 1](#) can be achieved. To ensure that the particulates control device is operating efficiently, the opacity of the flue gas leaving the stack shall be maintained below the stipulated limit.

5 Monitoring Requirements

To ensure that the emissions of contaminants from an incinerator are within the stipulated limits, the following monitoring requirements are considered to be essential. Any additional monitoring may be required by the Regional Manager on a site specific basis.

5.1 Continuous Monitoring

5.1.1 Monitoring Instruments Specifications, Locations and Maintenance

The performance specifications of the above continuous monitors for both operating and emission parameters shall be subject to approval by the Regional Manager. The locations of the monitors and the procedures for calibration, operation and maintenance of these instruments must be approved by the Regional Manager.

A monthly availability factor of at least 95% for each continuous monitor, with the exception of the hydrogen chloride monitor, is considered essential for data evaluation. For the hydrogen chloride monitor, a monthly availability factor of at least 90% is considered essential.

The Regional Manager must be notified of any continuous monitor failure for a period which may result in non-attainment of the recommended availability factor.

5.1.2 Continuous Monitoring Parameters

The following operating and emission parameters, applicable to all incinerator sizes, shall be monitored continuously:

1. Combustion Temperature;
2. Oxygen; and
3. Carbon Monoxide.

Additional continuous monitoring of emission and operating parameters listed below shall be required for incinerators of over 400 kg/h capacities:

1. Opacity;
2. Hydrogen Chloride; and
3. Emission Control Device Inlet or Outlet Temperature.

The above additional parameters shall also be monitored continuously for an incinerator of 400 kg/h or less capacity if it is equipped with an emission control system.

5.1.2.1 Combustion Temperature

The temperature at the fully mixed height in the final combustion zone of the incinerator shall be measured and recorded continuously. Temperature sensors shall be located such that flames from the auxiliary burners do not impinge on the sensors.

With respect to the continuous measurement and recording of the combustion temperature, a suitable and approved alternate location downstream of the final combustion zone may be acceptable, provided:

1. It is demonstrated that the temperature in the final combustion zone cannot be measured continuously without damaging the temperature sensors; and
2. A correlation between the final combustion zone temperature and that at the approved location downstream is established to the satisfaction of the Regional Manager.

5.1.2.2 Oxygen and Carbon Monoxide

Oxygen and carbon monoxide concentrations in the incinerator flue gas shall be measured at the same location downstream of the incinerator, but upstream of the emission control devices and where no dilution of the flue gas will occur.

It is recommended that the incinerator be equipped with automatic control and suitable alarm systems, preferably both visual and audible, in conjunction with the monitors for temperature, oxygen and carbon monoxide. The alarms should be set to ensure that whenever the minimum incineration temperature

and/or oxygen level drops below, or the carbon monoxide level exceeds, that recommended in [Table 2](#), auxiliary burner(s) should be turned on and/or the waste feed be discontinued automatically, until the normal operating conditions are reestablished.

5.1.2.3 Opacity

The opacity monitor should be equipped with suitable alarms set at an opacity level approved by the Regional Manager.

An alarm for excessive opacity level should be investigated for poor combustion of waste and/or malfunction of the particulate control device, and appropriate measures should be taken to rectify the situation.

5.1.2.4 Hydrogen Chloride

The continuous monitor for hydrogen chloride emission should be equipped with suitable alarms set at a predetermined hydrogen chloride concentration level approved by the Regional Manager. This monitor should be linked with the emission control system for acid gases, and the system should be adjusted automatically to reduce the emission, when the preset hydrogen chloride level is exceeded.

Alternatively, at facilities where continuous monitoring of sulphur dioxide is performed, a similar alarm and acid gas emission control system adjustment could be used to maintain the hydrogen chloride emission below the prescribed limit.

5.1.2.5 Emission Control Device Inlet or Outlet Temperature

The location of the sensor for continuous measurement of temperature at the outlet or inlet of the emission control device, depending on the particular emission control system in use, should be approved by the Regional Manager.

5.2 Source Testing

Within 90 days of the start of full normal operation of the incinerator, source testing shall be conducted for: oxygen, carbon dioxide and the contaminants listed in [Table 1](#) or Section [3.2.1](#), as applicable to a particular facility. The Regional Manager may require source testing of additional contaminants on a site specific basis.

The Regional Manager must be notified in writing well in advance of the actual testing. All source testing procedures shall be approved by the Regional Manager. Any subsequent source testing requirements will be determined by the Regional Manager based on his review of the initial source test results, continuous monitoring data and/or any other information related to the incinerator operation.

5.3 Other Monitoring

The following additional monitoring requirements are listed in general terms to encompass all facilities irrespective of the incinerator capacity. The Regional Manager shall determine the applicable items on a case by case basis.

5.3.1 General

The incineration facility shall be inspected daily by trained personnel to investigate the status of various components, so that malfunctioning of any components is identified and corrective actions are taken immediately. Such inspection should include, but not be limited to: waste and other materials delivery and storage area for spills, equipment leaks, corrosion, hot spots, gauges, monitors and recorders, etc. Records of daily inspection shall include the following items and any others which are considered to be necessary:

1. Inspection time and date;
2. Descriptions of the items inspected;
3. Observations made for each item inspected;
4. Any test, maintenance repair or any other corrective measures taken during or after the inspection; and
5. Inspector's name, position and signature.

5.3.2 Hours of Operation, Waste, Ash and Residue Handling

Records of operation of the incinerator and its ancillary facilities in hours per day shall be maintained. Daily records shall be maintained, in terms of weight, of quantities of:

1. Waste shipments delivered and their sources of origin;
2. Waste feed rate to the incinerator on an hourly basis or per batch, if the operation is in batch mode, and the number of batches per day; and
3. Daily rates of bottom ash, fly ash and/or residue generation and treatment, if any, and disposal.

5.3.3 Auxiliary Burner Operation

Records shall be maintained of operation of auxiliary burner(s) and the rate of auxiliary fuel used in each burner on an hourly basis for a continuous operation or on an "as used" basis, with the duration of each period, when operated intermittently. If the auxiliary fuel used is oil, then its source, type and sulphur content shall also be recorded for each batch of oil supplied. In no event shall the sulphur content in the auxiliary fuel exceed the limit stipulated in the current edition of the Sulphur Content of Fuel Regulation of the *Environmental Management Act*.

5.3.4 Emission Control Device

Records shall be maintained for emission control devices for removal of acid gases and/or particulates as follows:

1. Hourly average temperature at the inlet or outlet of the device, as the case may be, in degrees C;
2. Frequency and duration of any period when the device is not fully operational, and appropriate description of each period of malfunction of any device, as well as of the rectifying measure taken in each case;
3. Hourly average pressure drop in kPa across the wet scrubber and/or fabric filter;
4. Reagent chemicals used in kg/h by chemical; and
5. The volume of water used, if any, in m³/h.

The following additional records on an hourly basis shall be maintained for any separate particulates emission control device:

For fabric filter:

1. Average pressure drop in kPa across each module; and
2. Number of compartments in use.

For electrostatic precipitator:

1. Number of fields in use;
2. Applied voltage per field;
3. Current flow per field in amperes; and
4. Sparking rate per field.

5.4 Emission Control Device By-Pass Conditions

Records of relevant operating conditions during any discharge of flue gases by-passing the emission control device and the duration of such discharge shall be maintained.

6 Reports

6.1 Monthly Reports

For records of monitoring of items under Sections 5.1, 5.3 and 5.4 above, monthly reports shall be submitted to the Regional Manager within 20 calendar days following the end of each month.

The report for item [Section 5.1](#) shall include the following:

1. Data from each continuous monitor shall be tabulated in the specified averaging period for each parameter with both the minimum and maximum values recorded for each parameter during the

corresponding averaging period. The monthly average, minimum and maximum values for each parameter shall also be reported. Prior to discarding this data the Regional Manager shall be contacted regarding archiving;

2. Performance specifications and calibration data for each monitor;
3. Percentage of availability of each monitor;
4. Percentage of data capture for each monitor for the contaminants, oxygen and carbon dioxide;
5. The number of exceedances above the specified limit for each gaseous parameter and opacity, and the number of occasions when such exceedances lasted more than 1 hour, or the stipulated rolling averaging period for any particular parameter, with appropriate comments about remedial measures taken in each case;
6. The number of occasions when the combustion temperature dropped below 1000°C, and for each occasion indicate the recorded minimum temperature reached, the duration of operation at sub-1000°C temperature, and the corrective measures taken; and
7. The number of occasions when the flue gas temperature at the inlet or outlet of the emission control device exceeded 140°C, and for each occasion indicate the recorded maximum temperature reached, the duration of operation above 140°C temperature, and the corrective measures taken.

The records of monitoring of items under Sections 5.3.1 to 5.3.4 and Section 5.4 inclusive shall be summarized for the whole month in appropriate formats and submitted to the Regional Manager.

6.2 Source Testing Report

A complete report for the Source Testing ([Section 5.2](#)) results, with the exception of trace organics, shall be submitted to the Regional Manager within 60 days of the completion of the actual testing. The results for trace organics shall be submitted to the Regional Manager within 90 days of the completion of actual testing.

6.3 Annual Performance Report

An annual report reviewing the performance of the incinerator shall be submitted to the Regional Manager within 90 days following the end of a calendar year. The report shall contain evaluation of at least the following aspects:

1. The quantities of waste shipments received from different sources and waste processed at the site;
2. An overview of the plant performance describing the incinerator availability and the duration and causes of any non-availability; the status of operation and maintenance of various equipment and their adequacies; plant output, if any energy recovery is practiced; the quantities of bottom ash, fly ash and/or residue generated and their disposal methods; general housekeeping practices;

incidence of any emergencies and the response measures implemented; incidence of emission control system by-passing; and

3. Operation, performance and maintenance of emission control devices and continuous monitoring systems.

7 Start-up, Shutdown and Upset Condition Periods, and Spill Management

The owner or operator of an incineration facility shall prepare a detailed operating plan and procedures for the incinerator start-up, shutdown and upset condition periods, and submit it to the Regional Manager for approval prior to the issuance of a Permit. Such plan and procedures must be developed following the recommendations outlined in Appendix B and consultation with the equipment manufacturers, as necessary, so that the essential safety procedures for operation of any equipment are not overlooked or compromised.

Spill protection and/or reporting for the site shall be handled in accordance with the current edition of the Special Waste Regulation and/or Spill Reporting Regulation of the *Environmental Management Act*.

8 General Requirements for the Facility

8.1

The waste unloading and storage area shall be enclosed in order to minimize odorous and fugitive emissions. The area shall be designed and maintained on negative draft and in such a manner that the air from this area is used as combustion air for the incinerator.

8.2

The waste storage area shall be of sufficient capacity to store the delivered waste in the event of a shutdown of the incinerator due to malfunctions of equipment, labour dispute or any other interruption of operation.

8.3

The vehicular traffic areas at the facility shall be paved to minimize fugitive dust emissions.

8.4

Daily clean-up at the facility must be practiced so that any spilled waste or any other material is collected on a regular basis.

8.5

A standby electrical power generator of sufficient capacity must be available at the site to supply necessary power to maintain full operation of the facility in the event of a failure of the general electric power supply system. The standby electric power supply must be provided until the general electric power supply is restored or the incinerator is shut down in a manner prescribed in [Section 7](#) and [Appendix B](#).

9 Requirement for Training of Incinerator Operator

All incineration facilities subject to these Emission Criteria must be operated by properly qualified personnel. Copies of certificates of the operating staff verifying the satisfactory completion of a training program shall be submitted to the Regional Manager.

All incinerator operators shall be trained by a recognized technical organization or an institution with capabilities to provide necessary training in the operating practices and procedures of all equipment. The content of the training program shall be submitted to the Regional Manager for approval. The training program shall include, but not be limited to, the following:

1. The basic principles of waste incineration and emission of contaminants there from;
2. Knowledge of the Waste Management Permit requirements;
3. The basic features and location of the incinerator, emission control system, and other equipment at the facility;
4. Proper operation, functioning and maintenance of all mechanical, emission control and monitoring equipment;
5. Detection of excessive emissions and procedures to be followed during such occasions; and
6. Response procedures and measures to be taken during emergency situations.

This requirement does not eliminate the need for any staff involved with the facility from obtaining any other licenses or certificates necessary to carry out other duties as may be required by any other agencies.

10 Wastewater Management

Any wastewater generated at the site from the waste handling, storage and incineration area, any emission control system, ash and/or residue quench and conveyance systems, sanitary effluent, and from any other sources shall be treated and disposed of in a manner approved by the Regional Manager.

11 Ash and Residue Management

To minimize fugitive emissions of ash and residue particles, adequate precautions shall be taken at the time of handling, conveyance and storage of these materials. Wind-sheltered, enclosed storage areas shall be provided for these materials. As some of these materials may be classified as special waste, the final disposal methods for these materials must be approved by the Regional Manager. The disposal methods shall be determined after testing these materials in accordance with the procedures outlined in the current edition of the Special Waste Regulation of the *Environmental Management Act*.

Table 1: Stack Emission Limits for Incinerators of Capacity Over 400 kg/h of Waste

(Concentrations corrected to 11% O₂)

Contaminant	Limit	Averaging Period	Monitoring Method
Total Particulate	20 mg/m ³	(1)	(2)
Carbon Monoxide	55 mg/m ³ (3)	4-hour rolling average	Continuous Monitoring
Sulphur Dioxide	250 mg/m ³	(1)	(2)
Nitrogen Oxides (NO _x as NO ₂)	350 mg/m ³	(1)	(2)
Hydrogen Chloride	70 mg/m ³	8-hour rolling average	Continuous Monitoring
Hydrogen Fluoride	3 mg/m ³	(1)	(2)
Total Hydrocarbons (as Methane CH ₄)	40 mg/m ³	(1)	(2)
Arsenic (4)	4 µg/m ³	(1)	(2)
Cadmium (4)	100 µg/m ³	(1)	(2)
Chromium (4)	10 µg/m ³	(1)	(2)
Lead (4)	50 µg/m ³	(1)	(2)
Mercury (4)	200 µg/m ³	(1)	(2)
Chlorophenols	1 µg/m ³	(1)	(2)
Chlorobenzenes	1 µg/m ³	(1)	(2)
Polycyclicaromatic Hydrocarbons	5 µg/m ³	(1)	(2)
Polychlorinated Biphenyls	1 µg/m ³	(1)	(2)
Total PCDDs & PCDFs (6)	0.5 ng/m ³	(1)	(2)
Opacity	5%	1-hour average from data taken every 10 seconds	Continuous Monitoring

(1) To be averaged over the approved sampling and monitoring method.

(2) All sampling and monitoring methods, including continuous monitors, are to be approved by the Regional Manager.

(3) For RDF systems the limit shall be 110 mg/m³.

(4) The concentration is total metal emitted as solid and vapour.

(5) For existing incinerators the limit shall be 200 µg/m³, for the initial 2 years after the issuance of these Emission Objectives.

(6) Expressed as Toxicity Equivalents. The value shall be estimated from isomer specific test data and toxicity equivalency factors by following a procedure approved by the ministry.

Table 2: Design and Operation Requirements for Municipal Solid Waste Incinerators and Emission Control Systems

Parameter	Incinerator Type Modular (Excess Air and Starved Air)	Incinerator Type Mass Burn	Incinerator Type RDF
Incinerator			
Minimum Incineration Temperature	1000 degrees C at fully mixed height	1000 degrees C determined by an overall design review	1000 degrees C
Minimum Residence Time	1 second after final secondary air injection ports	1 second calculated from the point where most of the combustion has been completed and the incineration temperature fully developed	1 second calculated from point where most of the combustion has been completed and the incineration temperature fully developed
Primary Air (Underfire)	Utilize multi-port injection to minimize waste distribution difficulties	Use multiple plenums with individual air flow control	Use air distribution matched to waste distribution
Secondary Air (Overfire)	Up to 80% of total air required (1)	At least 40% of total air required	At least 40% of total air required
Overfire Air Injector Design	That required for penetration and coverage of furnace cross-section	That required for penetration and coverage of furnace cross-section	That required for penetration and coverage of furnace cross-section
Auxiliary Burner Capacity	Secondary burner 60% of total rated heat capacity, and that required to meet start-up and part-load temperatures	60% of total output, and that required to meet start-up and part-load temperatures	60% of total output, and that required to meet start-up and part-load temperatures
Oxygen Level at the Incinerator Outlet	6 to 12%	6 to 12%	3 to 9%
Turndown Restrictions	80 to 110% of designed capacity	80 to 110% of designed capacity	80 to 110% of designed capacity
Maximum CO Level	55 mg/m ³ @ 11% O ₂ (4-h rolling average)	55 mg/m ³ @ 11% O ₂ (4-h rolling average)	110 mg/m ³ @ 11% O ₂ (4-h rolling average)
Emission Control Systems (2)			
Flue Gas Temperature at Inlet or Outlet of Emission Control Device (3)	Not to exceed 140 degrees C	Not to exceed 140 degrees C	Not to exceed 140 degrees C
Opacity (4)	Less than 5%	Less than 5%	Less than 5%

(1) For excess Air type — as required by design.

(2) Applicable to incinerators equipped with such systems.

(3) The flue gas temperature at the inlet or outlet will depend on the type of emission control device in use.

(4) For incinerators with capacity or processing 400 kg/h or less of waste the opacity shall be less than 10%.

12 Appendix A

Acid Gases:

- Hydrogen chloride
- Hydrogen fluoride
- Oxides of nitrogen
- Oxides of sulphur

Chlorobenzenes (CBs):

- Cl-2 benzene
- Cl-3 benzene
- Cl-4 Benzene
- Cl-5 benzene
- Cl-6 benzene

Chlorophenols (CPs):

- Cl-2 phenol
- Cl-3 phenol
- Cl-4 phenol
- Cl-5 phenol

Polycyclic Aromatic Hydrocarbons (PAHs):

- Acenaphthylene
- Acenaphthene
- Fluorene
- Phenanthrene
- Anthracene
- Fluoranthene
- Pyrene
- Chrysene
- Benzo [a] anthracene
- Benzo [e] pyrene
- Benzo [a] pyrene
- Benzo [b] fluoranthene
- Benzo [k] fluoranthene
- Perylene
- Indeno [1,2,3-cd] pyrene
- Dibenzo [a,h] anthracene
- Benzo [g,h,i] perylene
- Benzo [l] phenanthrene

Polychlorinated Biphenyls (PCBs):

Polychlorinated dibenzo-para-dioxins (PCDDS) and polychlorinated dibenzofurans (PCDFs) in the following homologue groups:

- T — tetra
- Pa — penta
- Hx — hexa
- Hp — hepta
- O — octa

Appendix B: Recommendations for an Operating Plan and Procedure for Incinerator Start-up, Shutdown, and Upset Condition Periods

1 Incinerator Start-up and Shutdown

Without limiting the scope of the plan, provisions for the following must be included in the detailed plan and procedures:

1.1 Combustion Temperature and Waste Feed

The systems for waste feed, combustion control, and continuous monitoring of combustion parameters must be integrated in such a manner that proper incinerator operating conditions are maintained automatically. In addition, the procedures outlined below must be adhered to under the following circumstances:

1.1.1 No waste shall be charged to the incinerator until the required minimum temperature in the final combustion zone is achieved and maintained for at least 15 minutes by using the auxiliary burner(s).

1.1.2 In the event of any unscheduled or scheduled shutdowns:

1. The waste feed to the incinerator shall be automatically discontinued; and
2. The minimum required temperature in the final combustion zone shall be maintained by using auxiliary burner(s): (a) until the carbon monoxide concentration in the stack gas can be maintained below the required level, and the combustion and burndown cycles of the remaining waste in the incinerator are complete; and (b) for a minimum of 15 minutes from the beginning of an unscheduled shutdown and when an emergency discharge of the flue gas directly to the atmosphere becomes necessary.

1.2 Continuous Monitoring and Emission Control Systems

The continuous monitoring systems for combustion and emission parameters and emission control systems must be in proper operating conditions: (a) prior to any waste charging to the system during

start-up; (b) during normal operation of the incinerator; and (c) until the burndown cycle is complete at the time of any planned shutdown.

The emission control systems shall not be by-passed at any time when the incinerator is in operation, except under the following circumstances, if necessary, and during start-up and shutdown:

1. When the temperature of the flue gas at the emission control device is below or above that specified by the manufacturer; and
2. During an emergency shut down, for example, due to fire hazard or failure of the induced draft fan.

2 Upset Condition Periods

Some variations in the incinerator operating parameters and in the emission control parameters are to be expected; however, during normal operation of the incinerator the specified average values of these parameters can be maintained. Common indications of upset conditions may include but not be limited to:

1. An operating parameter which varies consistently for any unusual duration; and
2. The development of a trend towards a higher or lower value, as the case may be, than that specified for any particular parameter.

The incinerator operators must be trained to recognize abnormal operations as well as to take corrective actions in a systematic manner. A suggested list of potential measures is provided below; however, these measures should be reviewed with the manufacturers' specifications for the particular equipment installed at the facility.

2.1 Continuous Monitoring Systems

All continuous monitors and recorders should be checked for their performance and calibration by zero and fullscale span as applicable.

2.1.1 Combustion Parameters

In the event of low combustion temperature, low oxygen level and/or high carbon monoxide level, the following checks should be made:

1. Auxiliary burner(s) operation, including the fuel and air supplies;
2. The waste feed system;
3. Combustion air supplies to the incinerator;
4. Visual inspection of the incinerator grates; and
5. Other ancillary equipment which could influence the incinerator performance.

2.1.2 Opacity and Emission Control Parameters

During any exceedances of the flue gas temperature at the inlet or outlet of emission control device, of opacity, and of hydrogen chloride the following checks should be necessary:

1. The normalcy of the incinerator operation;
2. The flue gas conditioning system, if any, upstream of the emission control device;
3. Particulates emission control device; and
4. Acid gas scrubbing system.

2.2 Emergency Shutdown

Emergency shutdown procedures should be followed if the malfunctioning of the incinerator or emission control system persists even after implementation of the corrective measures to rectify any upset conditions.